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TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY OF GLASGOW.

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TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY

OF GLASGOW.

VOL. XV.

1912-1915.

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The Editors beg to state that the Authors alone are responsible for the facts and opinions contained in their respective papers.

PETER MACNAIR, F.R.S.E., F.G.S.
HARRY R. J. CONACHER.

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TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY OF GLASGOW.

No. I.—Notes on Buried River Channel at Motherwell.

By R. W. Dron, A.M.I.C.E.

[Read 14th November, 1912.]

The old river channel referred to in this paper is laid down on the 1-inch scale Geological Maps, sheets 31 and 23, and is referred to in the memoir to sheet 23 published in 1873.[1] It is also referred to in the "Summary of Progress of the Geological Survey" for 1911.[2]

The channel is first found at Cleland Townhead, and has been traced thence to Motherwell, a distance of 4 miles. Although doubtless it continues westward from Motherwell, the position has not yet been located.

On the 6-inch Geological Map (sheet xii., Lanarkshire) it is described as follows:—"Trough filled with clay, sand, and gravel (with boulder clay covering), pre-glacial and inter-glacial course of the Tillon burn."

From Cleland Townhead to Glencleland, a distance of 1¼ miles, the channel runs in a southerly direction, and the width shown on the map is 300 feet. This part of the channel has been proved by the old coal workings.

Near the junction of the Tillon burn and the Calder Water the old channel is intersected by the channel of the Calder. On the south bank of the Calder, near the viaduct carrying a mineral railway, there is here a very interesting exposure, where the gravel can be seen occupying the bed of the old channel.

[1] Pp. 50-51.
[2] P. 53.

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The channel now appears to turn towards the west. At Nether Johnstone sand quarry, three-quarters of a mile west from Glencleland, there is an exposure of sand and gravel which presumably occupies the site of the old channel. The section varies at different parts of the sand quarry, but at the north-east corner Mr. Clough gives it as follows:—

Boulder clay, 2 feet to 3 feet.
Gravel, 30 feet.
Sand, 15 feet.

A bore hole put down from the bottom of the pit passed through 100 feet of sand without reaching the bottom.[3]

In recent coal workings at Coursington colliery, Motherwell, situated about 1½ miles west from the Nether Johnstone sand quarry, the channel has been encountered. These coal workings have now proven its position and level throughout a length of over a mile.

At the Coursington colliery a tunnel has been driven into the bottom of the channel, and its level is there 90 feet above Ordnance datum. The surface level at the same point is 240 feet, so that the bed of the channel lies 150 feet below the present surface.

The surface level at Nether Johnstone sand quarry is about 300 feet, and, as the sand and gravel have been proved to a depth of 150 feet, the bottom of the channel must be at a level lower than 150 above Ordnance datum. At Glencleland the level of the channel bed, as exposed in the Calder Water, is about 270 feet above Ordnance datum.

At Cleland Townhead the level is about 490 above Ordnance datum.

From Coursington colliery to Nether Johnstone sand quarry the distance is 8000 feet, and in this distance the rise in the bed of the channel is less than 60 feet, or a gradient of 1 in 133.

From Nether Johnstone sand quarry to the crossing of the Calder at Glencleland the distance is 4000 feet, and the rise in the bed of the channel is more than 120 feet, or a gradient

[3] *Op. cit.* p. 53.

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of 1 in 33. From Glencleland to Cleland Townhead the distance is 6600, and the rise is 220 feet, or a gradient of 1 in 33.

The alteration of the gradient at Nether Johnstone sand quarry and the great depth of sand found there seem to suggest features which require further investigation.

In the underground workings at Coursington colliery no sand beds were met with. The boulders and gravel were generally rather coarse, varying in size from about 1 inch to 12 inches in diameter, and bound together with coarse sand. A considerable quantity of gravel from the opening was brought to the surface, and Mr. C. T. Clough made a careful examination thereof along with the writer.

The following is a list of the various classes of rock disclosed by this examination :—

1. Carboniferous sedimentary rocks, including Carboniferous limestone.

2. Dolerites like those composing the sheets or floats in various Carboniferous areas.

3. Porphyritic basalts, sometimes vesicular, like those comprising the contemporaneous Carboniferous lavas in the Campsie Fells, &c.

4. Slightly shistose grits, like those found along the southern border of the Highlands near Aberfoyle, Loch Lomond, &c.

5. Radiolarian cherts, like the Arenig cherts of the Southern Uplands.

6. Reddish felsite and quartz felsite, like those of Tinto Hill or near Carmichael.

7. Granite of a peculiar type, matching exactly that on Ballencleuch Law, 2 or 3 miles E.N.E. of Durisdeer.

The glacial striæ at Ballencleuch Law and Tinto point to the north, so that boulders from that district would be carried into the drainage area of the old channel. Similarly the striæ at Loch Lomond and Campsie Fells point to the east or south-east. From Ballencleuch Law to the position where the pebbles were found the distance is 33 miles, and from Aberfoyle about 30 miles.

The object of this paper is merely to place these facts on record, and the writer does not desire to draw any inference therefrom.

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No. II.—On an Occurrence of Dolomitic Limestone in Glen Fruin, Dumbartonshire. By the late Russell F. Gwinnell, B.Sc., A.R.C.Sc., F.G.S., Imperial College of Science and Technology, London.

[Read 14th November, 1912.]

On the north-west or Highland side of the great boundary fault which separates the Highlands from the Lowlands of Scotland there occur series of ancient rocks with roughly parallel outcrops, striking N.W. and S.E., and generally known as the Dalradian system. Though mostly consisting of altered sediments, the metamorphism of these sediments is by no means uniform, increasing, as it does, progressively both from the S.E. and from the N.W. towards a central axis.[1] Thus the alteration is very slight in the case of the slates and grits, which are immediately adjacent to the fault (or in places separated from it only by the narrow "Boundary Fault Series"). This series of little-altered slates and grits—the Aberfoyle series—is problematic as to its relationship with the Dalradian system. Usually regarded as among the oldest members of the system, it has been suggested by Professor J. W. Gregory that this series is either one of the youngest members of that system or else is post-Dalradian.[2] Apart from the grits, the Aberfoyle series consists mainly of phyllites, which are quarried for roofing slates at several places, such as Aberfoyle to the east and Luss to the west of Loch Lomond.

The Survey maps indicate local bands of limestone in the phyllites, but apparently no descriptions of these bands have been published. The rock described in this paper was from one of these limestone outcrops, in the bed of the northern branch of the small burn flowing down Craperoch and entering Fruin Water just above the farmhouse of West Kilbride, in Glen Fruin, Dumbartonshire.[3]

[1] Geology of Cowal, Mem. Geol. Surv. Scotland (1897), preface.

[2] *Trans., Geol. Soc., Glasgow*, xiv., part i., 24.

[3] Upper margin of one-inch sheet 30 and lower margin of sheet 38.

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The adjacent "slate" has been described by Mr. E. H. Cunningham-Craig[4], who remarks that it "shows a considerable development of more or less indeterminable micaceous minerals . . . along the cleavage planes. The bedding is marked by the presence of minute aggregates of quartz. . . . There has evidently been no crystallisation on more than a very minute scale; the rock has been deformed, and the constituents rearranged by dynamic metamorphism, but the constructive metamorphism is still at a minimum."

The limestone itself is black and lustrous with a greasy feel, soiling the fingers, and is strongly suggestive of a graphite schist rather than of a limestone. It is fairly soft, compact, with poorly defined lamination, and contains lenticles of harder material. One such lenticle measured about 2 by 3 by 6 centimetres, and consisted of a quartz aggregate. Other lenticles consist partly of quartz and partly of a flesh-pink rhombohedral carbonate. In specific gravity, specimens of the rock, which appeared to be free from these lenticles, averaged 2·85. Although the crushed rock effervesces appreciably with cold dilute HCl., there is abundant magnesium in the dissolved portion. As shown below, this result is probably due to the presence of calcite inclusions in dolomite crystals. The insoluble residue is indeterminable under the microscope, but in thin sections of the rock the microscope shows crystals of a rhombohedral carbonate, not exceeding 0·1 mm. in diameter, together with a clear mineral, probably quartz, and streaks of black opaque matter (? graphite). The carbonate appears to make up about three-quarters of the rock.

By crushing and partial separation of the constituents in water, and in other cases in bromoform, crystals of rhombohedral carbonate were obtained, varying from 0·01 to 0·05 mm. in longest diameter, the average being 0·02 mm. The lighter constituents consisted of quartz (? graphite), and a few red particles, possibly iron-stained felspar. Owing to the minute size of the rhombohedral crystals, reliable specific gravity determinations could not be obtained, but optical tests satisfactorily proved them to be dolomite, a result which accords well with the specific gravity of the rock as a whole (2·85).

[4] *Q.J.G.S.*, lx., 16.

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The crystals have the form of the unit or "cleavage" rhombohedron (1011), which is common in dolomite but rare in calcite, although it does occasionally occur in the latter mineral. The refractive indices of the crystals were determined by Schrœder van der Kolk's method, by immersion in a highly refractive liquid.[5]

Using monobromonaphthalene, of refractive index 8·66, and examining in polarised monochromatic yellow light, this method gave a very decisive result, in spite of the minute size of the crystals. The refractive index for the ordinary ray was distinctly higher than, and of the extraordinary ray much lower than, that of the liquid. This is in agreement with dolomite, but not with calcite.

A number of the crystals showed the characteristic zone of inclusions, surounded by clear dolomite. It is probable that these inclusions are of calcite,[6] a fact which would explain the abnormal effervescence of the rock in dilute acid.

The rock may perhaps best be described as a dolomitic limestone with graphite. In the Dunoon Phyllite series, which is correlated with the Aberfoyle series, there have been described black phyllites, which are probably somewhat carbonaceous, and in the same series many exposures of schistose limestone occur, but dolomite is not mentioned.[7] In another group of the Dalradian system—the Graphitic Schists—there occur bands of limestone and calcareous quartzites mixed with the schist.[8] No dolomite is mentioned, however, and, moreover, this group of rocks is only found at a considerable distance from the Aberfoyle series, as, for example, at St. Catherine's Pier, on Loch Fyne. In yet another group—the Loch Tay series—there occur limestones with very little magnesia. Mr. W. Ivison MacAdam[9] describes the rock quarried in Gleann Sluan, Argyllshire, wherein there is only 0·75 per cent. of $MgCO_3$. As already stated, Professor Gregory[10] regards the Aberfoyle

[5] See Idding's "Rock Minerals," first edition (1906), 117.
[6] C. G. Cullis, "The Atoll of Funifuti" (Royal Society, 1904), xiv., 408.
[7] Geology of Cowal, 9.
[8] *Ibid*, 53.
[9] *Trans., Edinburgh Geol. Soc.*, iv., 101.
[10] *Trans., Geol. Soc., Glasgow*, xiv., part i., 21.

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series as probably post Dalradian. He also regards the Torridonian as post Dalradian. Might it not be possible that the Aberfoyle series, with its abundance of grits, is of Torridonian age? The Torridonian is regarded as indicating an arid climate; under arid conditions dolomite is frequently formed, while hydrocarbon compounds are also characteristic of inland drainage, as pointed out by Mr. J. G. Goodchild in a paper on "Desert Conditions in Britain."[11] Another possible but unlikely alternative is that the Glen Fruin rock may really belong to the Border Fault series, which includes limestones in several places. These puzzling rocks have formerly been supposed by some authors to be Cambrian,[12] to which period, of course, belong the dolomitic limestones of Durness and Skye. Recent important discoveries of fossils, announced at the Dundee meeting of the British Association by Dr. Campbell and by Professor Jehu,[13] prove these rocks to be not older than Cambrian, and to be possibly Ordovician.. Finally, it is interesting to note that dolomite has been recorded by Mr. du Toit immediately on the Lowland or S.E. side of the Border Fault. In a paper "On Lower Old Red Sandstone Rocks of Balmaha-Aberfoyle,"[14] he refers to serpentine conglomerates, considerably older than the Old Red Sandstone, which are crushed and brecciated, portions being cemented together with yellow dolomite. At another spot the serpentine graduates into a foliated reddish ferruginous limestone or dolomite.

In the author's opinion, the Glen Fruin dolomitic limestone appears to be simply an unusually calcareous portion of a normally argillaceous deposit (the Aberfoyle or Dunoon slates); under exceptional conditions, direct precipitation of the rhombs of dolomite took place concurrently with sedimentation. The occurrence of similar minute rhombs of dolomite in the Keuper Marl is well known,[15] and occurrences of minute unit rhombs (either of dolomite or of other carbonates) assigned to contemporaneous precipitation have also been recorded from

[11] *Trans., Geol. Soc., Glasgow*, xi.
[12] J. W. Gregory, *loc. cit.*, 16.
[13] See *Nature*, 17th October, 1912, p. 209.
[14] *Trans., Edinburgh Geol. Soc.*, viii., p. 315.
[15] *E.g.*, C. G. Cullis, Rep. Brit. Assoc., 1907 (Leicester), p. 507.

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the Old Red Sandstone,[16] the Millstone Grit,[17] and recent deposits.[18]

A paper by the present author, read before the Mineralogical Society,[19] throws some light on the occurrence of inconstant calcareous bands in argillaceous sediments. Small unit rhombs, in this case of calcite, were abundantly formed during the dry summer of 1911 in a long leaden water pipe, when the slow trickling of the water favoured evaporation and consequent concentration of the dissolved salts. Since that drought the greater volume of water has prevented the further deposition of crystals, and in the cistern at the outfall the only sediment collected is a muddy deposit. Obviously the crystals were due to precipitation owing to concentration by evaporation, and *the opportunity for such concentration only occurs at inconstant intervals.* A similar explanation probably holds good in the case of the sporadically developed dolomitic areas in the mud rocks ("phyllites" or "slates") of the Aberfoyle series.

[16] Read 6th November, 1912 (not yet published).

[17] J. W. Gregory, "The Glenboig Fireclay," *Proc., Royal Society, Edinburgh*, xxx., part iv., p. 348.

[18] *E.g.*, A. Wade, "The Eastern Desert of Europe," *Q.J.G.S.*, lxvii., p. 238.

[19] "Calcite Crystals from a Water-tank," *Mineralogical Magazine*, vol. xvi., No. 77, July, 1913, pp. 345-7.

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No. III.—The Cowal "Landslip" of 5th August, 1912. By W. R. Smellie, M.A., B.Sc., Baxter Demonstrator in Geology, Glasgow University.

[Read 12th December, 1912.]

The use of the term "landslip" in the title of this paper demands explanation at the outset. Although no landslip, in the usual sense of the term, occurred, the phrase "Cowal Landslip" was so frequently employed in describing the damage wrought in Cowal at this time that it has been retained here in spite of its erroneous application. The damage (requiring £10,000 of the Cowal ratepayers' money to make it good) was so extraordinary that some term out of the ordinary had to be dragged in to describe it, although abnormal water transport accounts for practically all that occurred.

The affected area is bounded on the east by Loch Long, on the west by the west side of Loch Eck, and on the north and south by the Finart burn and the Holy Loch respectively, thus forming a parallelogram of about 20 square miles area. This district had suffered several days of more or less heavy rain previous to 5th August, so that the country was sodden and stream channels were taxed to their utmost to contain their torrents. While in this condition a very heavy thunderstorm burst over the area on the forenoon of 5th August, and this large and sudden addition to the volume of the already swollen streams was responsible for imparting to them the disastrous power of transport which inflicted the damage.

On examining the district it is seen that the changes wrought are of three main types, depending on the contour of the hills and the kind of stream draining them.

Type (1).—On very steep hillsides and usually at the foot of escarpments devoid of stream lines large clayey-coloured patches were evident. These were due to the escarpment resolving itself into a temporary waterfall, the force of the water tearing up the soil and spreading it like a pigment over the hillside below. These coloured patches, though frequently prolonged into temporary stream channels, seldom reached far

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down the hill, so that a new stream line was rarely formed. They present little in the way of permanent change, and the growth of next spring should obliterate all traces of them. The steep scarp slope formed by the schists on the west side of Loch Eck showed numerous examples of this type (see Plate I., Fig. 1). Only two cases are worthy of special mention, one south of Bernice Glen, Loch Eck, and the other just south of Sligrachan on the road between Whistlefield and Ardentinny. These were on a larger scale than the others, and much peaty mud, glacial débris, and a few trees were washed down, the one at Sligrachan burying the road to a depth of several feet. With the above two exceptions, these wash-outs were of little importance, and caused no damage.

Type (2).—Many of the steep hillsides in the area are drained mainly by numerous small streams, which come directly down the slope, and are devoid of any considerable tributaries. These streams have cut small V-shaped gorges, and the area drained by each is a strip of land little broader than the horns of the V. In such cases, since the drainage areas are small, the increase in volume and velocity could not have been excessive, yet it was sufficient to enable these streams to transport a great quantity of coarse sand and pebbles, which were deposited on the more level ground at the junctions with the main stream or loch. As the junctions usually occur just where the streams are led under the road made along the foot of the main valley, the loads were deposited over the road, the roofs of the inadequate underground channels being often broken through. Though the individual effects were insignificant, the total effect was very great, denying the road to vehicles and requiring much labour to repair. This will be evident when it is considered that one such stream crosses the road every few hundred yards. A good example of one of the larger streams of this type is seen in Plate I., Fig. 1. The gradient of such streams was found to be 1 in 2·6 in almost every case.

Type (3).—The third type wrought most havoc individually, afforded a much grander spectacular effect, and was of most interest geologically. After looking at one or two examples of this type in relation to the gathering ground of the stream, it was easy to see from the contours of the hills where others

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were likely to occur. The essentials were—(*a*) A comparatively large drainage area with the numerous head waters situated at approximately equal distances from the mouth of the main stream; (*b*) side streams with steep gradients, about 1 in 2·6, like those of type (2)—main streams with gradients which could be as low as 1 in 6; (*c*) stream debouching suddenly on to an almost flat alluvial plain. Given these conditions in any part

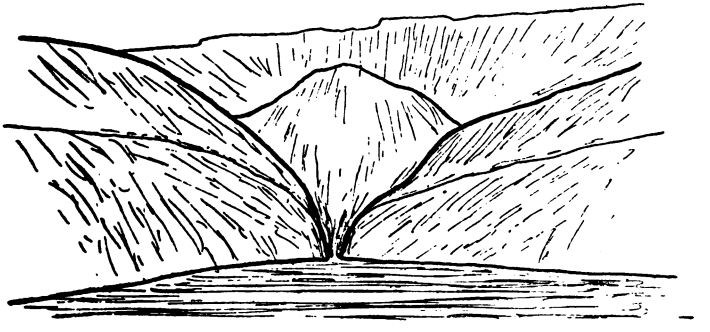

Diagram of Ideal Catchment Area to produce Type 3.

of the affected district and a disastrous transport of huge boulders (ranging up to 6 feet in diameter) was inevitable. Plate II., Fig. 1, of Barnacabben, Ardentinny, shows this type to perfection. The large gathering ground accounted for the large volume of water, the arrangement of the tributary streams ensured the simultaneous arrival of their contributions, and the gradients implied a very high velocity. The energy of a stream depends on the volume and velocity; it has been calculated to vary as the sixth power of the velocity; thus, if the velocity be increased several times, the lifting power will increase several hundred times. It is clear, then, how the boulder-strewn channels and banks were clean swept, large boulders, fixtures at ordinary times, being torn on with the others. On entering the flat alluvial plain the velocity was necessarily checked and the load dropped. These alluvial fans being usually the only inviting and fertile parts of flat country in the district had been chosen as sites for houses and cultivation, so that the phenomenal transporting powers of these streams were attended with much inconvenience and loss, the severity depending on the

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vagaries (akin at times to vindictiveness) of the particular stream. The localities where this third type was best seen were Inverchapel and Coylet, on the Loch Eck side, and Drynain, Barnacabben, and Ardentinny, on the side of the Finart burn and Loch Long.

Since the same general description applies to all, it will only be necessary to mention two where incidental peculiarities were exhibited—

Drynain.—Here, in addition to covering the alluvial fan with a fresh tumble of boulders, the stream changed its bed. Immediately on entering the level plain the former channel swung sharply round to the left, making a horse-shoe bend. During the flood the numerous boulders were travelling too fast to make this turn, with the result that a huge barrier, 10 feet high, was piled up across the bend (see Plate I., Fig. 2), thus forcing the stream to drive straight ahead, short cutting across the bend, and partially re-joining its old channel. This change of channel caused the partial overwhelming of one or two houses which had been built well back from the original channel, and apparently out of harm's way. The boulders strewn about averaged a foot in diameter; some were quite 6 feet, and on top of all several trees 30 feet long had been deposited.

Barnacabben.—Here the stream forked as soon as it met the alluvial plain, and just in the fork and facing the gully a small house was situated. As in the former case, the boulders, unable to divide with the stream channels, drove straight on and through the house, wrecking it utterly, and leaving only two battered, end-on gables rising from a heap of boulders (see Plate II., Fig. 2). The plain that the stream had to traverse before reaching the road was larger than usual, so that all the boulders were dropped long before the road was reached. Still, even bereft of this heavy ammunition, the water was sufficiently powerful to wash away the two well-built bridges which carried the road over the two branches of the stream.

Denudation Involved.—In considering the denudation, transport, and deposition accomplished by this storm, there is one principle insistently emphasised, namely, that streams, during a few hours' exceptional activity, can accomplish more

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work than they could in several decades at their ordinary rate. It would seem that the numerous alluvial fans in the district have been almost entirely built up by such storms, the long intervals between the storms serving only to fill up the interstices between the boulders with sand, and prepare a fresh crop of boulders in the upper reaches of the streams. The immense number of boulders deposited during this storm seemed difficult to account for, and tempted the explanation that they had merely been sorted and washed out of some incoherent glacial deposit. However, the absence of any such available deposit, and the fact that in each case at least 90 per cent. of the boulders were locally derived from within the catchment area of the particular stream, render it certain that the boulders represent so much actual denudation. This was further borne out by the upper parts of the channels being in places swept clear of boulders, while fresh pieces of rock were loosened and ready for the stream to wear into boulders to be brought down at the next storm. The amount of rounding suffered by the boulders during their transport was disappointingly small. The previous years of ordinary wear in the upper parts of the stream had rounded many of them thoroughly, but, with the exception of a few fresh bruises, there was nothing to show that these boulders had recently travelled in a tumbling mass of water and other boulders for a distance of at least a quarter of a mile. This would indicate that boulders owe most of their rounding to the grinding of sand and water, while they themselves are stationary, and by their own motion do little more than bruise off prominent corners.

Some Economic Points.—Both at Drynain and Inverchapel there was abundant evidence to show that this was not the first time in recent years that such a downrush of boulders had been experienced, and a study of the causes of the present catastrophe shows that there is no reason why such should not occur again, either in this or in similar districts. This being the case, it is evident that the alluvial fans of the type described should be looked on with suspicion as building sites. In general, they are the only inviting and available sites, but should be adopted subject to certain precautions. The site should be chosen as far as possible from the mouth of the gully which discharges

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the water on to the plain, and, in addition, should never be directly opposite the gully, even though the stream may have its channel well to the right or left. Having adopted these precautions, a wash-out with water and a plentiful deposit of sand is the worst that can happen, and complete destruction, as at Barnacabben (see Plate II.), is impossible. The position of the house shown in the plate illustrates perhaps the least desirable site possible; it is too far up the plain, and directly faces the gorge. The damage described here under type 2 also carries with it a lesson. The underground channels or culverts carrying the minor streams under the roads were lacking in two respects—(1) They were too small; with such streams to deal with, responding, as they do, so rapidly and vigorously to every heavy shower, the culverts should be made of a size greatly in excess of the ordinary requirements of the streams. (2) The slope of the floors of the culverts was negligible, so that the streams deposited their loads in the passages, broke the roofs, and overflowed the roads. If a gradient as near as possible to the natural gradient of the stream were continued underneath the road, the water could hold its load to a place where its deposition would cause no inconvenience. One or two culverts in the area came through the storm with credit, and it was noticeable that they were not lacking in the two essentials quoted above, although it must also be stated that they occurred on the Loch Eck side near the north of the affected area, which did not endure the full force of the storm.

The "landslip" gives an excellent illustration of the phenomenal transporting powers wielded by commonly small streams under increased volume and velocity. The extraordinary damage done by some streams is contrasted with the peaceful behaviour of others, also in the area, but lacking the required characteristics of gradient and form of catchment area. Lastly, it emphasises a point which applies to more than mere water erosion, and which is apt to be overlooked by people living in a country like ours, where the really gigantic forces are seldom loosed, namely, that in a few hours under abnormal conditions more work can be performed than normal denuding and transporting agencies could accomplish in many years, if, indeed, they could accomplish it at all.

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Fig. 2.
Drynain, Ardentinny—Barrier diverting stream.

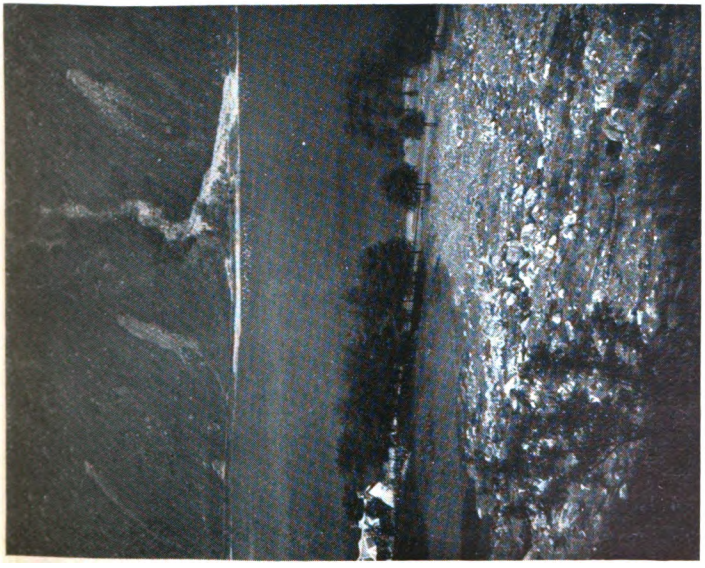

Fig 1.
Coylet, Loch Eck.

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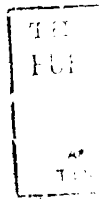

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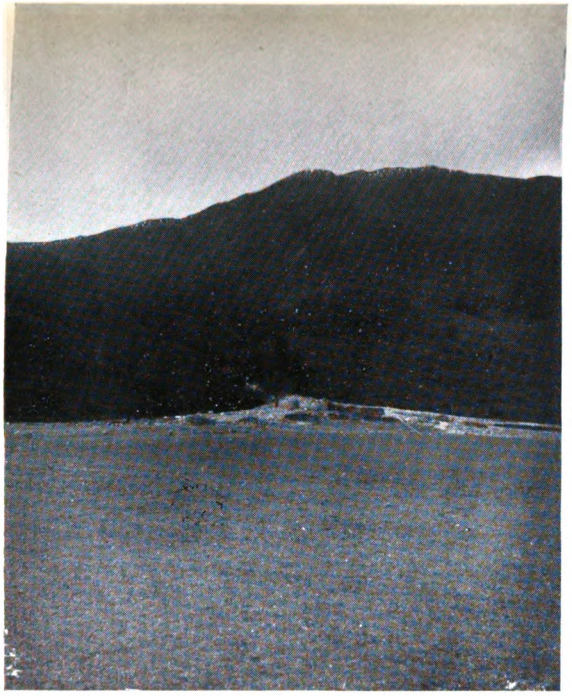

Fig. 1.

Barnacabben, Ardentinny. Note Cone of Desposition.

Fig 2.

Barnacabben, Ardentinny—side view.

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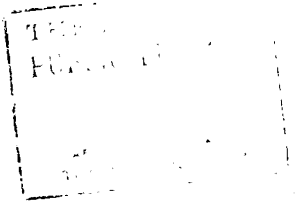

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EXPLANATION OF PLATES.

Plate I., Fig. 1.—Coylet, Loch Eck. Across the loch examples of types 1 and 2 are seen, while the foreground shows the debris of type 3 covering the alluvial plain.

,, Fig. 2.—Drynain, Ardentinny. This shows the barrier built across the sharp bend of the stream.

Plate II., Fig. 1.—Barnacabben, Ardentinny. This shows a good example of type 3.

,, Fig. 2.—Side views of same.

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No. IV.—The Pitchstones of South Arran. By Alexander Scott, M.A., B.Sc.

[Read 9th January, 1913.]

The pitchstones of Arran have been so well known for more than a century that further description may seem to require an apology. Except for Judd's description of the Drumadoon and Cir Mhor occurrences,[1] most of the previous investigations have dealt with the Corriegills rocks. The object of the present paper is to give a description of the glassy rocks and the felsites associated with them, which are found outwith the area treated in the Geological Survey memoir on North Arran, and to discuss shortly several of the more striking characteristics which they exhibit. The occurrences considered include the Monamore Glen sills and dykes, the Glen Ashdale composite dyke, the series of intrusions in the neighbourhood of Tighvein and the Burican pitchstone.

The Monamore Pitchstones.

The earliest notice of this series of intrusions occurs in Bryce's "Geology of Arran." In the edition published in 1859 no mention is made of it, but in the third edition, published about 1865, he describes two beds of pitchstone in "Moneadmhor Glen," associated with "claystones, hornstone, quartz-rock, and porcellanite."[2] Zirkel,[3] in his account of his journeyings in the Western Isles, mentions incidentally, in his description of the Corriegills and Tormore dykes, the same two intrusions, and notices that they contain thicker spherulites than is usual in this type of rock, and small green hornblende prisms, while associated with them is a "hornsteinähnliche felsit." Similarly, Allport[4] refers to them, but gives no details.

This series of intrusions comprises one felsite dyke and three pitchstone sills. The latter have been intruded along the

[1] *Q.J.G.S.* (1893), xlix., pp. 536-566.

[2] "Geol. of Arran," 3rd and 4th editions, pp. 156-158.

[3] Zeit. der deutsch geol. Gesellschaft (1871), xxiii., p. 41.

[4] *Geol. Mag.* (1872), ix., pp. 536-545.

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bedding planes of the Lower Triassic sandstones, and are well exposed in the bed of the stream which runs through the glen. The dyke occurs about 400 yards above the bridge which carries the Whiting Bay-Lamlash road over the burn, and it cuts through the sandstones, here dipping upstream at an angle of 10 degrees, in an approximately north and south direction. The dyke-rock is apparently a dark flinty felsite of rather fine texture, and somewhat jointed and broken. About 20 feet further upstream the first pitchstone sill occurs (see fig. on p. 31). The lower part consists of a bottle-green, non-spherulitic pitchstone with good conchoidal fracture, and joint planes so numerous that any attempt to determine its general direction is hopeless. This, however, is immediately overlaid by a light-coloured devitrified rock, which, at its upper margin, obviously passes, sill-wise, beneath the sandstones; and thus the whole, the thickness of which is about 30 feet, would seem to be a composite sill intruded in the sediments. Passing upstream from this place, there is an interval of a few yards of sandstone, and then, overlying this, is the second pitchstone sill. This is more complicated than the first one, and shows a considerable variety of rock, which, however, is always acid in composition. At the base there is about 25 feet of green pitchstone, immediately followed by 4 feet of hard green platy felsite, which, in turn, is succeeded by 9 feet of spherulitic pitchstone passing into a banded variety, and finally to a much devitrified rock of felsitic appearance. The last intrusion occurs at the Woollen Mill, and consists of a brown banded glass with abundant spherulites, and showing the effects of considerable devitrification, particularly towards the margins. At the upstream edge it seems to abut steeply against the sandstones, but at the lower it obviously overlies the sediments, in this case also a band of sandstone.

Microscopic Characters.

The rock of the dyke is a fine-grained basalt, with numerous phenocrysts of quartz and felspar, and xenoliths of a darker rock, also of basaltic affinity. As it has obviously no immediate

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relation with the pitchstones, and is probably of an earlier date, it will not be further described here.

The lowest pitchstone has a dusty brownish groundmass, in which are embedded scarce phenocrysts and numerous microlites. The former consist of felspar, which is usually a plagioclase approximating to normal oligoclase, magnetite, and some hydrated iron oxides which are decomposition products of a pyroxene. This rock has the banded structure which was noticed by Allport in the Tormore and Drumadoon[5] pitchstones, and which is also present in many of the Corriegills examples. The bands are of two kinds, a comparatively narrow one alternating with one several times as broad. The former consists of a clear glass with numerous rod-shaped crystallites, but free from complicated arborescent forms. These rods seldom appear single, but seem to be composed of an aggregate of belonites arranged with their axes in approximately parallel directions, and with the shortest in the centre, so that the ends present a bifurcated appearance and the whole resembles the crenulite[6] of Rutley. These are too small for the discrimination of cleavage, &c., but they are green in colour and anisotropic, with an extinction angle which varies from zero to 30 degs. By the growth of two or more of these from a common centre, cruciform and stellate forms develop, and, indeed, are more common than the simple forms. A prominent characteristic of these bands is the presence of innumerable idiomorphic crystals of magnetite, generally in euhedral cubes, and accompanied by small belonitic structures growing out from them in radial directions.

In the other bands the clear glassy base is rendered a dusty brown colour, owing to the presence of numerous greenish longulites, which give a low extinction angle, and are probably of a hornblendic nature. In addition, there are many larger microlites, each surrounded by an area of colourless glass. Structurally these may be divided into two types, which are well known from the descriptions of Zirkel,[7] Allport,[8] Rosen-

[5] *Geol. Mag.* (1872), ix., pp. 1-10.
[6] *Min. Mag.* (1891), ix., p. 261, &c.
[7] Zeit. der deutsch geol. Gesellschaft (1871), xxiii., pp. 42-46.
[8] *Geol. Mag.* (1872), ix., pp. 1-10, 536-545.

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busch,[9] &c.[10] While both have composite main axes of parallel belonites arranged in a step-like fashion, they differ in the arrangement of the subsidiary axes. In one type these grow out from the principal axis at all points, and the skeleton crystal ultimately assumes an arborescent form, while in the other type the outgrowths are confined to the two ends of the principal axis, which otherwise is free from excrescences.

Passing upwards from the base, the flow structure, as indicated by the parallelism of the belonites becomes more pronounced and devitrified patches begin to appear. The latter are much stained with iron oxides, and have usually at their centre a crystal of felspar, which is often so corroded that little of it remains. Another exposure of this pitchstone a few yards to the south shows these structures much more prominently. The basal pitchstone of the second sill very much resembles this one, save that the majority of the microlites assume a different form, being composed of radial bunches of rods, usually curved, and growing out from a crystal of quartz or sanidine or a single belonite axis. In the latter case the microlites are similar to the axiolites of Zirkel.[11] Arculites[12] are also present, but the other forms predominate.

The upper rock of the first sill is an indistinct, much devitrified glass with decomposed microlites, phenocrysts being rare, and always corroded. A remarkable feature is a number of parallel bands, which cross the rock in a direction approximately coincident with that of the microlites. The structure is somewhat complicated, but a prominent characteristic is a series of longitudinal aggregates of green anisotropic crystals, two occurring side by side in each band, surrounded by a yellowish-brown area of still smaller crystals. Where a phenocryst occurs in a band, the latter widens out and passes round the former, which in many cases has been resorbed, and is represented by a devitrified area showing spherulitic extinction in polarised light, as do the outer margins of the bands. Most of the phenocrysts are aggregates of quartz and felspar, while

[9] Micro. Physiog. d. massigen Gést., p. 700, &c.
[10] Teall, Brit. Petrogr., pp. 344-347, &c.
[11] Micro. Petr., 40th par. (1876), pl. vi., fig. 2.
[12] Rutley, *loc. cit.*

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several narrow felsitic veins of these minerals traverse the rock in irregular directions.

The second pitchstone of the upper sill is a banded rock, which originally was probably very like the non-porphyritic variety of the Corriegills rocks,[13] but which is now devitrified to a considerable extent. The glassy groundmass is filled with belonites and skeletal microlites, while a few anhedral crystals of felspar and augite occur, the former showing very fine lamellar twinning, and resembling anorthoclase. The augite and the microlites have been altered sometimes to iron oxides, and the glass devitrified, chiefly along flow bands and in subsidiary directions perpendicular to these. The central axis of these "schlieren" bands is a narrow line of green non-pleochroic chloritic crystals like those occurring in the previous rock. On each side is a broad, clear area, with low double refraction, traversed by numerous secondary axes, and composed of spherulitic masses of quartz and felspar. This becomes more dense and opaque towards the outside margins, which are usually delineated by an aggregate of somewhat decomposed microlites standing out in relief against the undevitrified glass. That this development of crystalline structure, which also appears round the phenocrysts, took place long after the formation of the microlites, and hence after the rock had cooled, is shown by the fact that these are found independently of the bands, and, indeed, often crossing the boundaries of the latter. Passing upwards from the base, the amount of devitrification decreases, and the upper part is a perfectly fresh and unaltered microlitic pitchstone. It is traversed by a large number of microscopic lines—about fifty to the centimetre—which are approximately parallel, and, at first sight, look like scratches.* They are made up of aggregates of dark green crystals of a hornblendic nature, resembling those of the upper part of the first sill. In the latter rock the green crystals, originally pyroxene or hornblende, seem to have altered to chlorite during the devitrification of the rest of the base. While in both cases

[13] v. Harker, Petrology, 4th ed. (1908) p. 119, footnote.

* That these are not scratches is shown by their perfect parallelism and by the preparation of other slides—on rotating discs—which showed the same structures.

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the microlites cut through the bands in all directions, the unaltered rock shows that their development is anterior to the crystallisation of the base, as incipient devitrification is only found locally where the glassy margin of the band is altered to a cryptocrystalline aggregate.

The uppermost rock of this sill may be described as a devitrified felsite, and changes in the space of a few inches from a dark, spherulitic, banded variety to a light green one, with no banding or spherulites visible in the hand-specimen. It has originally been a non-porphyritic pitchstone with numerous microlites, which are now much decomposed and changed to amorphous hydroxide of iron, while the groundmass is made up of a devitrified mass of quartz and felspar—the former predominating—which is sometimes spherulitic, sometimes apparently granophyric. The dark layers in the hand-specimen are represented in thin sections by lighter non-microlitic bands of felsitic appearance. The rock is exceedingly siliceous, and seems to be made up of quartz and amorphous limonite, with subordinate felspar, which cannot be discriminated owing to the cryptocrystalline structure.

The Woollen Mill rock presents a more remarkable appearance than any of the other Monamore intrusions. The small portions of the base which remain undevitrified show that it was originally a colourless glass with many large crystals of felspar, which contain numerous orientated inclusions of the matrix, and are partly sanidine and partly a basic oligoclase. A few crystals of magnetite may represent original pyroxene or hornblende, but the greater part of the iron has separated in an amorphous form during devitrification, as in many cases the isotropic glass is coloured a deep brown by limonite and hæmatite staining. There are numerous ferromagnesian belonites, which seem to be of two kinds, one extinguishing at an angle of about 30 degs., while the other shows practically straight extinction. The rock is very much altered by devitrification, which has commenced along cracks and schlieren bands and round the felspar crystals, and is pronouncedly spherulitic. The outside margins of the devitrified areas are delineated by a continuous series of elliptical arcs of dark limonitic material, with a lighter band immediately inside these. In a fresher sample of this

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rock, found in the Rutley collection, this margin is composed of green crystals, apparently of a chloritic nature. In other parts of the rock incipient devitrification has produced many elaborate radial and spherulitic structures.

The Glen Ashdale Composite Dyke.

The dyke on the south side of Glen Ashdale is exposed on the escarpment which marks the boundary of the Dippin teschenite. It strikes approximately north-north-west, and can be traced for about 70 yards to the southward, but cannot be followed on to Torr an Loisgte, which is composed of another branch of the Dippin sill. The dyke is composite, the two marginal parts, each about 3 feet thick, being pitchstone, while in the centre is about 8 feet of felsite. The hade is about 40 degrees to the south-west, and the rock is little jointed or broken, while the junction between the two varieties is perfectly sharp, there being no gradual transition from the one to the other. Megascopically the marginal rocks are very similar in appearance, both being green pitchstones with subconchoidal fracture. The eastern one, however, has not so pronounced a lustre as the western, and is somewhat lighter in colour, while both are traversed by a number of dark parallel bands. The central rock is a grey spherulitic felsite, in which small quartz and felspar crystals can be detected. The arrangement of the spherulites tends to produce a banded appearance, while the rock has an irregular fracture, and is often coloured brown, owing to limonite staining.

Microscopic Characters.

The "eastern" pitchstone is composed of a glassy base crowded with rod-shaped microlites and smaller "dusty" belonites, and with numerous phenocrysts of quartz, felspar, pyroxene, and magnetite. The quartz is generally found as well-shaped crystals surrounded by hyalite areas with "brush" extinction, and an intermediate tridymite layer as described by Judd,[14] although in this case the structure is not so pronounced

[14] Judd, *Q.J.G.S.* (1890), xlvi., p. 380.

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as in the Cir Mhor rock. Microlites are common in the inner of the two hyalite bands, but very scarce in the outer. The felspar occurs as euhedral triclinic crystals with the characteristics of oligoclase, and having, in common with the quartz, frequent inclusions of apatite, magnetite, and augite. The pyroxene is an ægirine augite of intermediate composition showing slight pleochroism. The phenocrysts are found in glomeroporphyritic aggregates, and have undoubtedly been formed under plutonic conditions, the pyroxene being surrounded by the quartz and felspar.

The larger microlites are single green prisms with no pleochroism and a good cleavage, which is apparently rectangular, while the extinction varies from 40 to 50 degrees. They show the properties of a pyroxene, and there is no doubt as to their identity as one of that group. Subordinate to these are clusters of cruciform growths of smaller belonites, which average in length ·01 millimetre, while the larger microlites vary from ·6 to ·03 mm. The base is otherwise a colourless glass, save where, in the neighbourhood of corroded quartz crystals, devitrification has been induced, probably by local silicification following on re-solution of the quartz. The rock of the western margin is very similar, except that the microlites are smaller, averaging ·06 mm., while they are invariably surrounded by a clear "court of crystallisation."

The central rock consists of quartz and felspar phenocrysts in a cryptocrystalline aggregate of the same minerals. The quartz occurs in well-defined hexagonal crystals, with rounded angles, while the felspars are likewise euhedral, and are mainly sanidine, together with a little anorthoclase. The base is a characteristic granophyric intergrowth, except in the neighbourhood of the quartz crystals, which are invariably surrounded by a spherulitic development consisting of brown radial fibres interspersed with a number of decomposed belonites. There are two concentric bands of these fibres, differing in refractive index and double refraction, which in both cases is lower than that of quartz. The fibres are probably hyalite, and the variation in the optical properties is due to a difference in the water content, the brown colour being caused by limonite. The structure is not found round the felspar nor the small,

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almost colourless, ægirine which is occasionally present. Hæmatite is also found in skeletal forms, and may be pseudomorphous after ilmenite.

The Tighvein Dykes.

The series of dykes which occur to the south and east of Tighvein have many things in common, and may be considered together. The An Sloc intrusions have been treated in detail by Corstorphine,[15] and little can be added to his description. These are two parallel dykes trending in a north-west and south-east direction, one at the confluence of the An Sloc and a small tributary on the north side, and the other some distance further up the main stream. The former cuts through the felsite porphyry, and the latter through the basalt which composes the southern part of the Tighvein complex, and the dykes are indifferently exposed in the centre of an area covered by peat. Both rocks are green pitchstones with splintery fracture, the upper showing quartz and felspar, while the lower has a dull, aphanitic appearance.

Microscopically the rocks show phenocrysts of quartz, felspar, and pyroxene in a groundmass of "microlitic" glass. The felspar is the most abundant, and comprises plagioclase and subordinate orthoclase and microcline. The quartz and felspar occur in subhedral crystals, with numerous inclusions of glass, augite, enstatite, zircon, and rutile. The pyroxene is found as small euhedral crystals of augite, which is often twinned, and strongly pleochroic enstatite. Rutile altering to leucoxene, pyrites, and magnetite occur as scarce accessory minerals.

The groundmass may be divided into three parts—

(*a*) Layers of glass rendered opaque by the presence of innumerable longulites and occasional skeletal forms..

(*b*) Lighter bands, crowded with belonites arranged in radial aggregates, and containing plumose microlites.

(*c*) Spherulitic areas round quartz and felspar. These are usually bordered by a dark brown ring, with a similar, but double, band in the middle of the crystalline aggregate. Corstorphine[16] identifies the minute particles which make up

[15] Tschermak's Min. Mitt. (1894), xiv., pp. 480-450.

[16] *Loc. cit.*

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these bands as rhombohedral crystals of chalybite formed by the decomposition of glass under the influence of carbon dioxide. It seems more probable that they are aggregates of hæmatite and limonite as decomposition products of femic minerals similar to those described above in the margins of devitrified parts.

About half a mile east of these intrusions another pitchstone dyke cuts through the felsite in an east and west direction near the source of the Allt nan Clach, a tributary of the Kilmorie Water. The rock closely resembles those described above, and a separate description is unnecessary.

Another dyke, unmarked in the one-inch Geological Survey map, is seen in the eastern branch of a tributary of the Allt Dhepin, about 600 yards west of Loch na Leirg. Its thickness cannot be measured, as only one face is exposed, forming a small waterfall in the stream, and trending in a N.N.W. direction. It is a greyish-black porphyritic pitchstone, with numerous light-coloured spots, and a pronounced platy fracture parallel to the vertical edge. It is traversed by numerous thin veins of felsite up to 3 inches in thickness, and roughly parallel to the walls of the dyke. The dyke, with a north-west and south-east direction which outcrops on the path about one-third of a mile south-west of the Urie Loch, is identical with the above, and would seem to be its continuation. The maximum thickness here exposed is about 20 feet. Microscopically the rock is a pitchstone porphyry with phenocrysts of quartz, plagioclase with regularly arranged inclusions, pyroxene, which is partly a zoned augite and partly enstatite, olivine,[17] and magnetite. There are two generations of crystallites in a glassy base, the larger being green pyroxenic belonites with no pleochroism and a high extinction, and the smaller, brown indefinite longulites. The latter occur in aggregates as the outer margin of a band of hyalite, which is usually found round the euhedral quartz and felspar, but not round the pyroxenes. As in the Cir Mhor rock, a narrow layer of tridymite occurs in the hyalite, but very near the outer margin. The base of the longulitic bands is occasionally anisotropic, and has probably undergone devitrification to some extent.

The felsite, which traverses the main rock, has a blue-grey

[17] For description of olivine, *see* page 26.

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flinty appearance, altering in parts to a light-coloured modification, and occasionally porphyritic. Microscopically the rock consists of a cryptocrystalline groundmass with phenocrysts of quartz, felspar, decomposed pyroxene, olivine,[18] and magnetite. The quartz is found as perfect euhedral crystals surrounded by hyalite, but the tridymite is absent. The felspar is apparently a basic oligoclase which is very much sericitised, while the groundmass is mainly a felsitic intergrowth of quartz and felspar, with, in some parts, a graphic structure, in others a spherulitic. Decomposed microlites are common, and a little uncrystallised glass is also present.

The only other pitchstone which will be described is the Burican rock, which outcrops in Sliddery Water just above Glenrie Bridge. The pitchstone forms a ledge about 20 feet thick at the junction of a felsite sill and the sediments, and is probably the upper part of the sill, which here seems to come up along the junction of the Upper and Lower Trias.

Microscopically the rock is a glass rendered opaque by minute microlites and with many aggregates of phenocrysts, comprising quartz, felspar, pyroxene, olivine, and magnetite. The quartz and felspar, which is a rather basic oligoclase, are found as euhedral crystals with abundant inclusions, which are often regularly orientated. Round the crystals occurs an anisotropic double band, which seems to be rather decomposed hyalite, while the dark band in the middle may represent tridymite. The pyroxene is an ægirine augite with a fairly high extinction, and hence much nearer the augite end of the series. The larger belonites are likewise pyroxene, with the same properties, and are surrounded by a clear area of glass, as in the western margin of the Glen Ashdale dyke. Forms intermediate in size between the belonites and the phenocrysts are also found, so that there is no doubt that the belonites are augite. In addition, there are a number of greenish crystals with high refractive index, and altering to serpentinous material. They resemble olivine very much, and a careful measurement of their double refraction proved them to be fayalite. The crystals show slight pleochroism from green to greenish-yellow, and alter in part to serpentine, in part to hæmatite, which is more trans-

[18] *See* page 26.

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lucent than that mineral usually is. The olivine which is mentioned above in the description of the Allt Dhepin rock shows the same characters. Olivine is exceedingly scarce in acid rocks, and it is somewhat difficult to account for its co-existence with quartz in a pitchstone. Iddings[19] describes the occurrence of olivine and tridymite in lithophysæ in rhyolite and obsidian in the Yellowstone Park, as well as in some acid volcanic rocks from Lipari.[20] Penfield and Forbes[21] also found olivine in granite in Massachusetts. Olivine, as an orthosilicate, is unsaturated with respect to silica, and consequently a mixture of olivine and quartz under magmatic conditions would in general result in the formation of enstatite or hypersthene, according as the forsterite or fayalite molecule preponderated in the olivine. Under certain particular conditions, of course, magnesium or iron monoclinic pyroxenes or amphiboles might form. The glomeroporphyritic arrangement of the phenocrysts in the rocks under consideration precludes the action of magmatic vapours, as is postulated in the case of the obsidian lithophysæ.* In these rocks the phenocrysts are of such dimensions and euhedral forms that they must have crystallised under plutonic conditions,[22] and at a time long anterior to the period of intrusion, as is shown by the resorption of the quartz. Hence, while it is impossible to tell whether the phenocrysts are merely porphyritic or truly xenocrystic, they may for all practical purposes be considered as the latter. The fact that the resorption is confined to the quartz shows that the holocrystalline portions have not been subjected to a high temperature, as, if they had, they would undoubtedly be dissolved, and such anomalous mixtures as quartz and olivine reprecipitated as pyroxene. It is significant that the crystal aggregates may be divided into two groups, one containing quartz, felspar, and pyroxene, and the other pyroxene, olivine, magnetite, and some felspar. Hence the two following possibilities regarding the origin of the olivine suggest themselves:—

(*a*) That the glomeroporphyritic aggregates are wholly or

[19] Am. Jour. Sci. (1885), 3rd ser., vol. 30, p. 58.
[20] Am. Jour. Sci. (1890), 3rd ser., vol. 40, p. 75.
[21] Am. Jour. Sci. (1896), 4th ser., vol. 1., p. 129.
* *See* Note at end of Paper.
[22] *cf.* Judd, *Q.J.G.S.* (1890), xlvi., p. 380.

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partly of xenolithic origin, and that the olivine originally crystallised from a basic magma which was subsequently inundated by siliceous material.

(*b*) That the formation of the olivine is analogous to that of magnetite in a granite.

Of these two, the first seems the more satisfactory, as the great chemical reactivity of the olivine, both in the molten state and in solution, militates against the second hypothesis, as does the fact that, with the exceptions mentioned above, olivine practically never occurs in granite. Again, most of the igneous rocks of the south end of Arran,[23] like those of Skye,[24] are undoubtedly of a hybrid nature, being formed of a granitic and a gabbro magma. Thus, the most probable conclusion is that the olivine-bearing parts of the rock are of xenolithic origin.

Occasionally the groundmass is doubly refracting as small spherulites occur, similar to those described by Harker[25] in the dyke at Wreck Bay, Rum.

The rock of which the pitchstone is probably a differentiation facies may be classed as a spherulitic quartz felsite, as it is composed of quartz and subordinate felspar in a base which has numerous spherulites with interstitial cryptocrystalline material. The material of the spherulites, which are perfectly ellipsoidal in shape, has a refractive index lower than that of quartz, and seems to be a mixture of felspar with large amounts of hydrated silica, probably of a hyalitic nature. The interstitial material sometimes develops granophyric structure, and numerous crystals of tridymite occur. These have now been replaced to a great extent by quartz, which develops owing to tridymite being a metastable modification of silica at ordinary temperatures. The spherulites are exceedingly well shaped, and probably in none of the other Arran pitchstones is such perfect development found.

Pitchstone and Felsite.

Since the only rocks which are found in the intrusions which we have considered are pitchstone and felsite, an examination

[23] Geol., North Arran.
[24] Tert. Ig. Rocks, Skye, pp. 169-197.
[25] Geol., Small Isles, p. 179.

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of the genetic relations of the two types will probably assist in the interpretation of the composite nature of the dykes and sills. That little can be learned from the chemical analyses is shown by a consideration of the following table,[26] in which the numbers represent the lower and upper limits of the percentages of the various constituents of the two rocks:—

	Pitchstone.	*Felsite.*
SiO_2	65 – 80	60 – 81
Al_2O_3	·5 – 14	9 – 19
Fe_2O_3	tr. – 3·4	·4 – 3
FeO	tr. – 1·7	0 – 5
MgO	0 – ·3	0 – 3
CaO	·5 – 2·5	0 – 4·5
Na_2O	·3 – 5·5	·2 – 5·8
K_2O	1 – 5·1	·3 – 7·1
H_2O	·7 – 12·3	·7 – 5·2

The word "felsite" is used very loosely, and may designate any one of half a dozen types, such as devitrified pitchstone, quartz porphyry, ceratophyre, &c. These may be divided into two classes, those which arise through the devitrification of glasses and those which crystallise directly from the magma. Since a glass is merely a highly undercooled liquid, and therefore has a thermodynamic potential much higher than that of the crystalline phase, it is theoretically possible for all pitchstones to devitrify. That this is the case in Nature is proved by the rarity of glassy structures in palæozoic rocks. Various suggestions have been put forward to account for the difference in structure. Lagorio[27] believed that many glasses have approximately a eutectic composition, since this would involve the minimum melting point, and hence the maximum viscosity. Vogt[28] maintains that the presence of alumina has a similar effect, but Morozewicz,[29] on the other hand, starting from the physical-chemical law that an unsaturated solution will not readily deposit crystals, holds that a deficiency in alumina favours the formation of glasses. The primary things to be considered as effective in the process of cooling are temperature and pressure. Since Vogt has found that pressure has little direct effect on the solidification of

[26] Compiled from Prof. Paper No. 14 of U.S. Geol. Survey.
[27] Tscher. Min. Mitt. (1887), viii., p. 421 *et seq.*
[28] Silikatschmelzlösungen. Bd. 2.
[29] Tscher. Min. Mitt. (1898), xviii., pp. 1-20.

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systems, such as quartz, orthoclase, albite, &c., we need only consider the temperature effects. Rapid cooling is in favour of the production of pitchstones, and so long as the rate of cooling exceeds the velocity of crystallisation glasses form. Again, acid magmas are generally highly viscous, and any conditions which entail the postponement of solidification to a low temperature likewise increase the viscosity. The two other factors which exert an influence in the same direction are the absence of mineralisers and the presence of an excess of soda in the magma. To sum up the main points, quick cooling and high viscosity, however induced, tend to favour the formation of glassy rocks, while slow cooling and low viscosity favour crystalline rocks.

In the case of the Glen Ashdale dyke the felsite may have crystallised as such during the process of cooling, since the spherulites are probably true ones, and Harker[30] has stated that true spherulites do not in general form as the result of devitrification. In this instance the best explanation seems to be that the felsite was intruded up the centre of a pitchstone dyke which had not completely cooled, and hence the centre rock underwent a comparatively gradual decrease of temperature, since the conductivity of a glass is fairly low, and the base solidified in a cryptocrystalline condition. Harker[31] describes the development of spherulites in a very similar rock at Boreraig, Skye.

In the Monamore rocks, on the other hand, all the felsites are probably the result of devitrification. Structurally the rocks may be divided into two classes—A, C, E^2 are pitchstones; B, D, F are devitrified rocks; while E^1 may be considered as a transition form. Partial analyses have been made, and, while the whole sequence show several features in common, such as high alkali and low lime and magnesia content, they differ to some extent in the amounts of silica and alumina. The first group are all acid, and contain from 10 to 12 per cent. alumina and about 73 per cent. silica, while B and F are sub-acid, with 65 per cent. silica and 14 per cent. alumina. We have here a series of successive intrusions at very short intervals from the same magma, although, at the same time, some slight

[30] Geol., Small Isles, p. 181.

[31] Tert. Ig. Rocks, Skye, p. 281; also pl. xxii., fig. 1.

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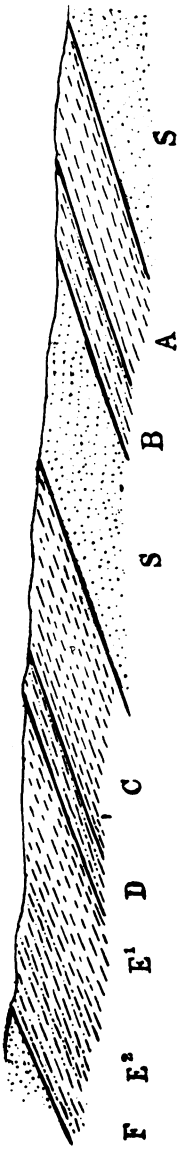
differentiation has taken place. While this undoubtedly had some influence in determining the amount of the devitrification, several other factors have been at work, as in E we have a gradual passage from an almost pure glass to a devitrified rock. The experiments of Bonney[32] show that a re-heated glass tends to crystallise very readily; further, that the presence of crystalline nuclei of the same molecular composition as the materials of the glass, and the existence of flow bands or other strain structures increase the tendency to devitrification. There is no doubt that the devitrified layers in these rocks occur along fluxion bands, while the areas round the phenocrysts were in a state of strain owing to the unequal contraction of the crystal and the glass during cooling. Daubrée[33] found that, if the re-heating were conducted in the presence of water vapour, crystallisation could be induced more easily, and he came to the conclusion that the presence of water, combined with the increase of pressure was the main factor. None of these rocks show the perlitic structure which is so characteristic in the

[32] *Q.J.G.S.*, 1885. Proc. p. 84.

[33] Synthetische Stud. zur experimental Geologie, 1880.

SECTION IN MONAMORE GLEN.



DESCRIPTION OF FIGURE.

S, sediments, 30 feet thick between sills; A, pitchstone, 20 feet; B, devitrified felsite, 10 feet; C, pitchstone, 25 feet; D, platy felsite, 4 feet; E^1 and E^2, spherulitic pitchstone, partly devitrified, 24 feet; F, devitrified rock, about 10 feet.

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Meissen and Hlinik[34] glasses, and which Allport[35] used to determine the original nature of the palæozoic Shropshire felsites. The Geological Survey describe a felsite from Glen Cloy[36] which shows ferruginous and chloritic decomposition products of the microlites, and this structure is taken to be evidence of devitrification. The presence of these developments in the rocks under consideration, as well as the general relationships and chemical composition of the series, tend to show that we have a number of successive intrusions, and that the felsites were the earlier products from the magma, the devitrification being due to the different chemical composition, the re-heating and changes in pressure due to the subsequent intrusions, and finally the probably greater content of water and other mineralisers.

It has been assumed hitherto that the microlites of the majority of the Arran pitchstones[37] are hornblende, although in Skye Harker[38] notes the exceptional occurrence of augites. Where simple belonites develop, the optical properties can often be determined, and hence the mineral identified, as in the case of the pyroxene crystallites of Glen Ashdale and the hornblendes of many of the Skye rocks.[39] It has been argued that the presence of augite phenocrysts favours the pyroxenic nature of the microlites. The relationships between hornblende and pyroxene, however, show that the co-existence in one rock of the two modifications of similar chemical composition is not incompatible with a comparatively simple cooling process. Consideration of equilibrium curves shows that a melt which would deposit pyroxene crystals under certain conditions would, under other conditions of temperature and pressure, deposit hornblende. The latter is the low temperature modification, while pyroxenes form at high temperatures and tend to pass into hornblende as the temperature falls, though the transformation is very

[34] A. Sauer. Zeit. deut. geol. Ges. 1888, xl., p. 601 *et seq.* O. Stutzer. Monatsb. deut. geol. Ges. 1910, pp. 102-113, pp. 205-214.

[35] *Q.G.J.S.* (1877), xxxiii., pp. 449-460.

[36] North Arran Memoir, p. 126.

[37] Allport, *loc. cit.*, and *Geol. Mag.* (1881), p. 438. Zirkel, *loc. cit.* Judd, *loc. cit.*

[38] Tert. Ig. Rocks, Skye, p. 406.

[39] Tert. Ig. Rocks, Skye, p. 403 *et seq.*

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readily inhibited and difficult to effect. While the phenocrysts in these rocks formed under plutonic conditions, the formation of the microlites took place anterior to the final cooling, as is proved by the presence of a fluxional arrangement and the clear glass round the microlites, which shows that diffusion was still possible. As pitchstones may be assumed to have undergone a rapid fall in temperature and pressure in the process of solidification, the microlites develop immediately antecedent to, or very early in, this cooling process, while the much smaller longulitic growths arise in the later stages of cooling, perhaps when the rock was in the labile condition, when they would originate from lately formed globulites, which are to be regarded as minute spherical drops of supersaturated solution, and as essentially not crystalline.[40] Hence the nature of the microlites would depend on the particular temperature and pressure at the time of formation, and also on the degree of supersaturation of the magma with respect to the femic silicates under these conditions.

The complicated arborescent and plumose structures belong to the same generation as the belonites, and are merely skeletal developments of these. The three factors which favour the growth of skeletal forms are the rapid evaporation of solvent, viscosity, and low degree of concentration or solubility.[41] In the case of rock magmas the first of these may be neglected. Since the rate of growth at any point varies as the concentration gradient in the immediate neighbourhood, it follows that in a solution of high viscosity cooling rapidly skeletal forms must develop, owing to the velocity of crystallisation tending to exceed the rate of diffusion. The second and third factors mentioned above have the effect of hindering diffusion, and their operation is well exampled in the pitchstones of the Sgurr of Eigg[42] and Oigh-sgeir and of Monamhor Glen respectively. In the latter case we have a small quantity of femic material dissolved in a solvent mixture of quartz and felspar molecules. The degree of supersaturation necessary for the crystallisation of the femic silicates is only reached when the magma is viscous,

[40] Vogelsang. Die Krystalliten.
[41] Vogelsang, *loc. cit.*
[42] Geol., Small Isles, p. 179.

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and the low concentration and high viscosity, combined with the great velocity of crystallisation, prevent the filling in of the spaces between the axes, and the result is a skeletal growth. The determination of the mineralogical nature of these fern structures is exceedingly difficult, though many of the Arran ones appear to give straight extinction. The globulites from which these structures arise must be assumed to have a certain crystallising force, which varies for different directions. Vogelsang has termed the directions of greatest attraction the maximal axes, and the main axis of a crystallite is usually one of these. Since these, however, are not necessarily coincident with the crystallographic axes, optical constants determined with reference to them are of little value. In this connection Corstorphine[43] applied an ingenious chemical method, and proved the An Sloc microlites to be hornblende. It seems very probable that a similar conclusion would be reached in the other cases.

With regard to the existence of the "hyalitic" areas round the quartz phenocrysts, the identification of the fibrous material as hyalite and the intermediate layer as tridymite is due to Judd,[44] but he offered no explanation of the phenomena. While this development is certainly later than that of the phenocrysts and of the larger microlites, it is probably antecedent to the formation of the longulites, and thus took place during the process of cooling. In most cases the material has been derived from the surrounding glass, and not from the phenocryst, as the latter has usually perfect outlines, and has not suffered corrosion, which would result in rounded angles owing to the different solution pressure on different faces. The question of the tridymite further complicates matters. According to the researches of Day and Shepherd,[45] silica appears in about six modifications, and of these tridymite, in its two forms, is stable above 800 degs. C. The fact that many of the microlites in these rocks are hornblende, as well as the comparatively late development of the tridymite, would indicate that other conditions for the formation of the latter must be sought. Konigsberger and Müller[46] ascertained the effect of heating obsidian with water under different conditions of pressure, &c. By an

[43] *Loc. cit.*
[44] *Q.J.G.S.* (1893), xlix., p. 550.
[45] Am. Jour. Sci., 4th ser. (1906), xxvi., pp. 265-301.
[46] Cent. für Min. (1906), p. 663, p. 735.

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ingenious filtering arrangement they found that at 360 degs. the rock decomposed and quartz and opal separated from the solution, while tridymite was formed in the undissolved residue. Quensel[47] concludes that opal and hyalite are the modifications of silica stable at low temperatures in the presence of water, and that the equilibrium between quartz and tridymite is greatly affected by the presence of co-solutes. On the other hand, Leitmeier[48] considers opal to be a gel of inconstant composition and varying properties, and quartz and chalcedony to be intrinsically the same. Lately phase diagrams have been worked out for silica, but, unfortunately, the only forms included are glass, quartz, and cristobalite,[49] and hence the conclusions are not applicable to complexes containing tridymite and hydrated modifications. Chrustschoff,[50] using a mixture of silica and a solution of hydrofluoboric acid, obtained cristobalite at 180-230 degs. C., quartz at 240-300 degs. C., and tridymite at 310-360 degs. There is no doubt that the occurrence of tridymite in the hyalite areas, as well as interstitially in the Burican felsite, is to be explained partly by the presence of co-solutes, such as water, and partly by the fact that the formation of tridymite involves a smaller diminution in volume than the formation of quartz.[51] As the former mineral is metastable at ordinary temperatures, it is finally transformed to the more stable quartz. Owing to the diffusion of silica to the pre-existing quartz crystals, the magma in the immediate neighbourhood must have been enriched in silica and water, and it is easy to understand how, on cooling, the water originally dissolved in the molten silica should become colloidally absorbed in the hyalite gel. Any complete explanation of the formation of the single layer of tridymite, however, is impossible until the equilibrium of the system silica water has been thoroughly investigated.

In conclusion, I wish to express my great indebtedness to Mr. G. W. Tyrrell for his kindness in lending me his specimens and field notes, as well as for much assistance in many other ways.

[47] Cent. für Min. (1906), p. 370.
[48] Cent. für Min. (1908), p. 637.
[49] Smuts and Endel. Zeit. für anorg. Chem. (1913), 80, pp. 176-184.
[50] Neues Jahrb. für Min. (1897), p. 1, p. 240.
[51] Endell and Rieke. Zeit. für anorg. Chem. (1912), 79, pp. 239-259.

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NOTE TO P. 13.—The idea that the formation of orthosilicates in the presence of free silica may be due to the hydrolitic effect of hydrogen at high temperatures does not seem valid here in view of the absence of small olivines, while the "xenocrystic" theory is aided by the fact that the crystals are much corroded and somewhat uniform in size. Hydrolitic action between water and silica, however, may explain the small crystals of fayalite.

DESCRIPTION OF PLATES.

Plate III., Fig. 1.—Base of 2nd sill, Monamore Glen. Shows the banded structure described on page 18, and spherulitic development of crystalline material round the partly resorbed crystal of felspar. ×25.

,, Fig. 2.—Composite plumose microlite as described on page 18. ×125.

,, Fig. 3.—Single arborescent microlite as described on page 18. ×125.

,, Fig. 4.—Axiolite with longulitic groundmass. ×125.

,, Fig. 5.—Pitchstone, 1st Monamore sill. Crystals of felspar surrounded by partly devitrified band (dark area) with isotropic base beyond. ×30.

,, Fig. 6.—Banded pitchstone, 2nd Monamore sill. Shows isotropic glass with microlites and line of minute pyroxene crystals along a flow-band. ×30.

Plate IV., Fig. 7.—Woollen Mill pitchstone, Monamore Glen. Continuous band of spherulites along a joint-plane (or flowband) with isotropic base on each side. ×30.

,, Fig. 8.—Woollen Mill pitchstone, Monamore Glen. Ring of spherulites round a plagioclase crystal. ×30.

,, Fig. 9.—Glen Ashdale dyke, western margin. Shows glomeroporphyritic arrangement of phenocrysts of quartz, oligoclase, and augite, with trace of perlitic structure and small belonites with "court of crystallisation." ×15.

,, Fig. 10.—Glen Ashdale dyke, eastern margin. Shows fluxion arrangement of pyroxenic belonites. ×15.

,, Fig. 11.—Pitchstone-porphyry, Loch na Leirg. Plagioclase crystals with orientated inclusions and hyalite areas round the margins; the dark crystals are augite. ×15.

,, Fig. 12.—Spherulitic quartz-felsite, interior of Glen Ashdale dyke. Crystals of quartz surrounded by double band of dark fibres of siliceous material in cryptocrystalline base. ×30.

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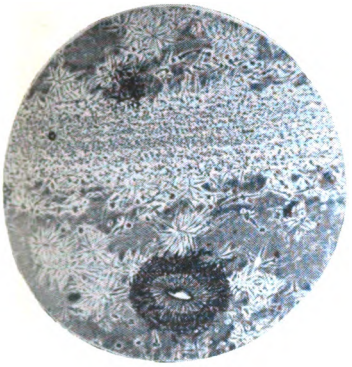

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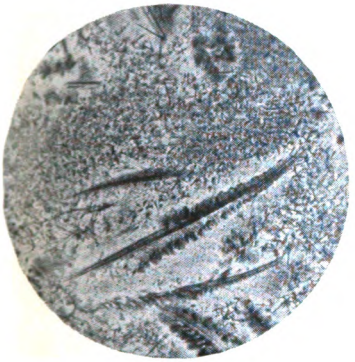

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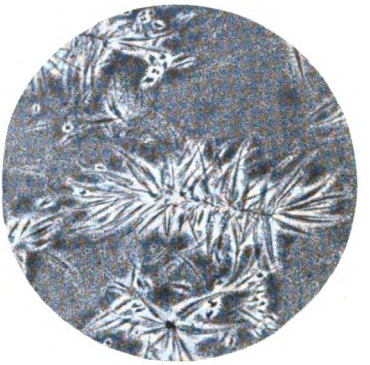

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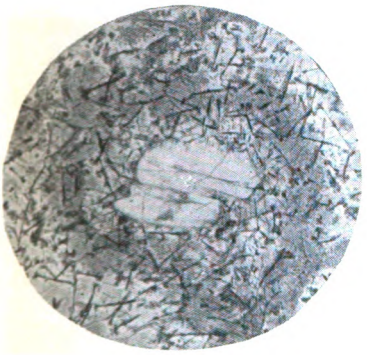

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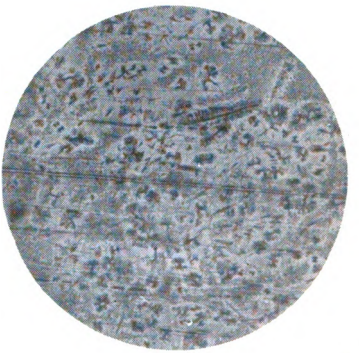

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Photomicrographs of Pitchstones.

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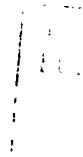

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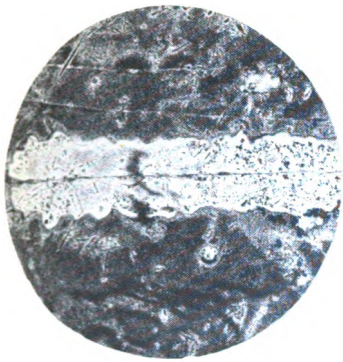

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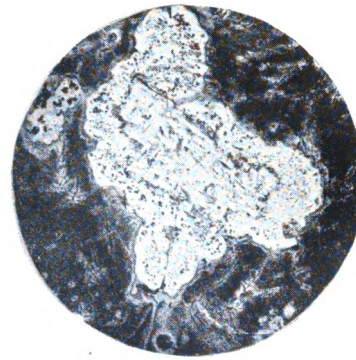

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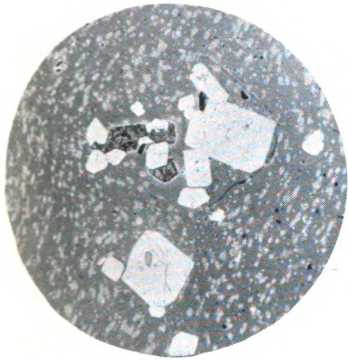

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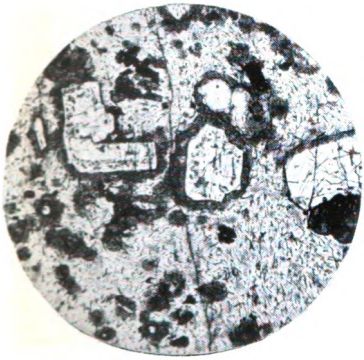

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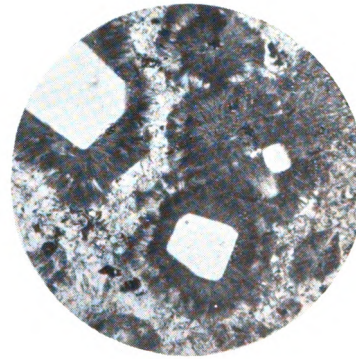

12.

Photomicrographs of Pitchstones.

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No. V.—The Stratigraphy of the Limestones Lying Immediately above the Calciferous Lavas in the Glasgow District.

By Peter Macnair, F.R.S.E., F.G.S., and Harry R. J. Conacher.

[Read 13th March, 1913.]

The group of sediments under discussion is that commonly known as the Lower Limestones, with the addition of those which occupy the space between the base of the Hurlet Seam and the top of the lavas, that is, from the Hosie Limestones at the top to below the Hollybush. These limestones crop out practically all around the basin in which Glasgow lies, and are seen in burn sections, quarries, and railway cuttings along the base of the hills of Calciferous lava which form its rim.

The strata below the Hurlet Seam are grouped by the officers of the Geological Survey with the Calciferous series, but as there is no essential break at this horizon in our district such as exists in the Lothians, we propose to deal with all these beds as one series.

The district dealt with may be defined as including Hurlet, Howood, Paisley, Bridge of Weir, Duntocher, Bearsden, Campsie, Kilsyth.

The literature of the subject is meagre. There are references in the Geological Survey's publications dealing with Sheet No. 31 of their 1-inch Geological Map.[1] In the *Transactions* of our Society there is a paper by Mr. Hugh M'Phail dealing with the Barrhead-Paisley District;[2] there is Dr. Young's paper of 1860 on Campsie and the Glasgow District;[3] and there is the Memoir of the Geological Survey, published in October, 1911.[4]

[1] Memoirs of the Geological Survey, Scotland. Explanation of Sheet 31 (1879).

[2] On the Carboniferous Sections of the Levern Valley, Renfrewshire. *Glas. Geol. Soc. Transactions*, vol. iii., p. 254.

[3] On the Geology of the Campsie District. *Trans. Geol. Soc. Glas.*, vol. i., p. 1, 1863.

[4] Memoirs of the Geological Survey of Scotland. The Geology of the Glasgow District, 1911.

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Prior to the issue of the last-named publication, no definite co-relation of the beds under discussion had been published. It was while going over the ground with that book in hand that we came on the points which we now bring before you.

Hurlet District.—In the Memoir, the following horizons are recognised and described in the district, and may be examined at the localities named:—

Hosie Limestone—River Levern at Barrhead.

Blackhall Limestone—Jenny's Well, Paisley, and Levernside, Crookston.

Hurlet Limestone—Not now seen, except at Arkleston Cutting, north-east of Paisley.

Blackbyre Limestone—Railway Cutting at Barrhead.

Hollybush Limestone—Hollybush Quarries, and Hawkhead Dam.

With regard to the Hosie Limestone at Barrhead, we are unable to offer any opinion or criticism of this identification.

The Blackhall Limestone, as seen at Jenny's Well (first described by Mr. John Smith in vol. xii. of our *Transactions*), shows definite and constant characters which enable it to be recognised with certainty throughout the district. It is in several beds, the top one marine, the lower fresh water, and contains a parting of entomostracan oil shale. It can be seen to overlie a series of clay-band ironstones, which, again, are above the Hurlet Seam, as shown by old workings.

The Blackbyre Limestone, as seen in the railway cutting at Blackbyre Farm, is also in several beds, the upper composed of small encrinite fragments, and the lower slabby and crowded with small producti and containing occasional plant remains.

The Hollybush Seam is accessible with difficulty in the old quarries at Hollybush and below high-water level in the Hawkhead Dam. In both localities its most striking characteristic is the abundance of large producti (*giganteus*, *latissimus*, and *semi-reticulatus*), and branching and solitary corals.

The stratigraphical relations of the Blackbyre and Hollybush Limestones cannot be certainly seen in the type district, but the positions assigned to them in the Memoir are confirmed by neighbouring sections, which are now described for the first time.

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Nethercraigs.—At Nethercraigs, south of Paisley, there is a small syncline, truncated to the south by the fault which brings up the lavas of the Ferneze Hills, and in this basin—no more than half a mile across—we see the Hurlet Limestone, the Blackbyre, and the Hollybush. The Hurlet Limestone, which at Hurlet is stated to be no more than 4 to 5 feet thick, has here increased, by the addition of limey shales, to about 30 feet. This is a surprising phenomenon, but it is also seen to occur at Howood, in the Gryfe, and at Campsie. The

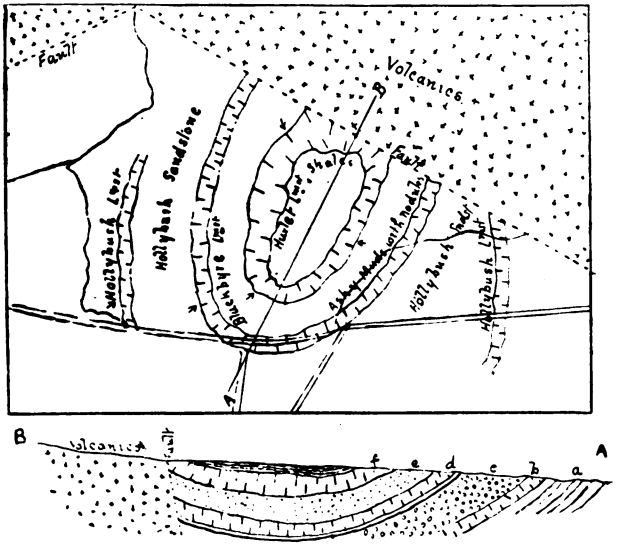

Fig. 1.—Plan and Section across Limestones at Nethercraigs, Paisley. (*a*) Strata below Hollybush Limestone; (*b*) Hollybush Limestone; (*c*) Hollybush Sandstone; (*d*) Blackbyre Limestone; (*e*) Ashy muds with limey nodules; (*f*) Hurlet Limestone.

alum shale and coal, which usually underlie the encrinital Hurlet Limestone, are not seen here, but a very characteristic brecciated limestone bed with ashy mud, recognised by us in the same position at Howood, Bridge of Weir, and Campsie, is well displayed in old quarry section and in the neighbouring burn. Below it comes a thickness of sandstone whose lower boundary is a line of unconformity, which is also seen in the Campsie district. The Blackbyre Limestone comes in at this

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point and is, as elsewhere, a typically marine deposit. The beds underlying it are seen in the burn section to consist mainly of sandstone with thin coal (the "Lady Anne"), and then comes the Hollybush Limestone. This seam is not well seen in section, but it contains the typical large producti and corals. At Nethercraigs the burn section goes only a short distance below the Hollybush, showing nothing but sandstone, but at Hollybush we get a glimpse in burn and railway sections of volcanic muds and oolitic beds which seem everywhere to occupy a position immediately above the lavas. There are also some ironstones containing plant remains.

Howood.—In old quarries here, and in a burn section at Meikle Corseford, we find the Hurlet Limestone exhibiting the Nethercraigs characteristics and immediately underlain by a shale and coal. Some parts of the shale contain a marine fauna (producti, &c.), while others are matted with a lamellibranch which appears to be *Cypricardia* (*Sanguinolites*) *tricostata?* The peculiar brecciated limestone is seen in the burn, and it here contains a few marine fossils, and is overlain by an ashy bed with nodules, like that of Nethercraigs. The equivalent of the Blackbyre Seam is also exposed, but differing somewhat in character from that of the type. Below it sandstone appears, overlying limey beds which are crowded with giganteid producti and lithostrotion, which we regard as the equivalent of the Hollybush. Unfortunately the section gives no certain information beyond this point, and the boundary fault comes in. The modification of the characters of the Blackbyre Limestone seen in this section is interesting as confirming the identification of the small, isolated exposure of limestone seen in the railway cutting at Auchinback, east of Barrhead, providing a link in the transition of this bed from the characters seen in the type section to those prevailng at Thorntonhall and in north Ayrshire.

Bridge of Weir.—In the Gryfe, to the north-east of Bridge of Weir, there is an excellent section which, with but one important gap, is complete from the top of the lavas to the top Hosie Limestone. Beginning at Bridge of Weir and working down stream, there is an interesting section of muds and conglomerate of lava pebbles lying in hollows on the

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eroded lava surface. Above this comes ashy fireclay, with rootlets, irregular coal, and greenish sandstone. A horizon of fossiliferous nodules and shales then comes in, which is found to develop into a fairly compact limestone in places, crowded with large producti and branching corals. It can be examined at intervals along the banks of the Gryfe from the cottage on the west bank to the ford. At the latter place the

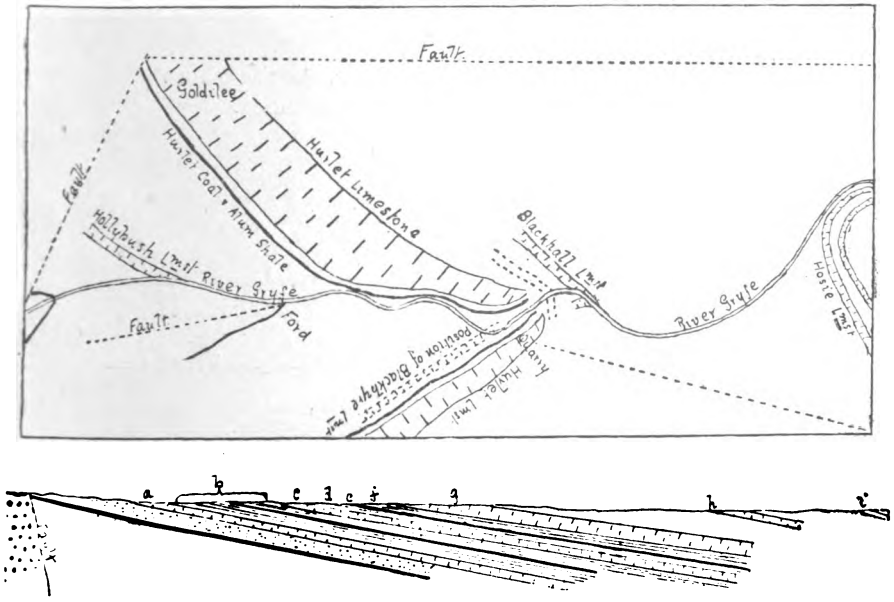

Fig. 2.—Plan and Section along the Gryfe, from Bridge of Weir to Crosslee. Lettering same as tables in text (see page 42).

nodular phase is well seen. This limey horizon overlies a thin coal. A sill penetrates the strata, and the sequence is obscured by small disturbances which run parallel to the line of section. From the ford to the turn in the stream at the old limestone workings, there are no exposures, but below water level at the sharp bend, the nodular green limestone can be seen, containing corals and encrinites. The coal and alum shale are not now exposed, but fragments can be picked up in the bings. The evidence for identifying this seam as the Hurlet is fairly

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complete, and as already mentioned, this section also displays the augmentation of its thickness by the addition of limey shales, while the more typical encrinital part, 4 to 5 feet thick, has been worked out. The gap in this section occurs below the nodular green bed, just described, and we believe that at this point the Blackbyre Limestone exists, which opinion is confirmed by the evidence of the following bore put down at Goldilee and quoted in the *Transactions* of the Highland and Agricultural Society:—

BORE AT GOLDILEE, BRIDGE OF WEIR, RENFREWSHIRE.
CORRELATED WITH THE HURLET SECTION.

	Feet.	Inches.	
Clay,	12	0	
Flag,	20	0	
Limestone,	7		*g* Hurlet Limestone.
Till,	1	0	*f* Alum Shale.
Coal,	2	6	*e* Hurlet Coal.
Fire-clay,	5		*d* Ashy Muds with Limey Nodules.
Limestone,	4		*c* Blackbyre Limestone.
Fire-clay,	2		
Black Till,	19		
Coal,		10	*b* Equivalent of Hollybush Sandstone.
Grey Till,	13		
Greenstone,	5		Intrusive Sill.
Grey Till,	5		*a* Hollybush Limestone.
Freestone,	5		
Coal Till,		9	
Coal,	1	3	
Fire-clay,	5		
Whinstone,			Lavas.

The limey beds, containing large producti and corals, we correlate with the Hollybush Seam.

Proceeding with the stream, a small fault is crossed, which brings down the top of the Hurlet, and then the shales and ironstones, with a thin coal, are met. These are overlain by a very interesting series of strata, of which we give a detailed section—

h {
18″ encrinital limestone.
14″ strong shale.
12″ shale or fireclay with stigmaria and entomostracan shale.
12″ entomostracan limestone.
}
12″ shale.
4″ coal.
Shale with ironstones (containing *Lithostrotion* in places) and coal.

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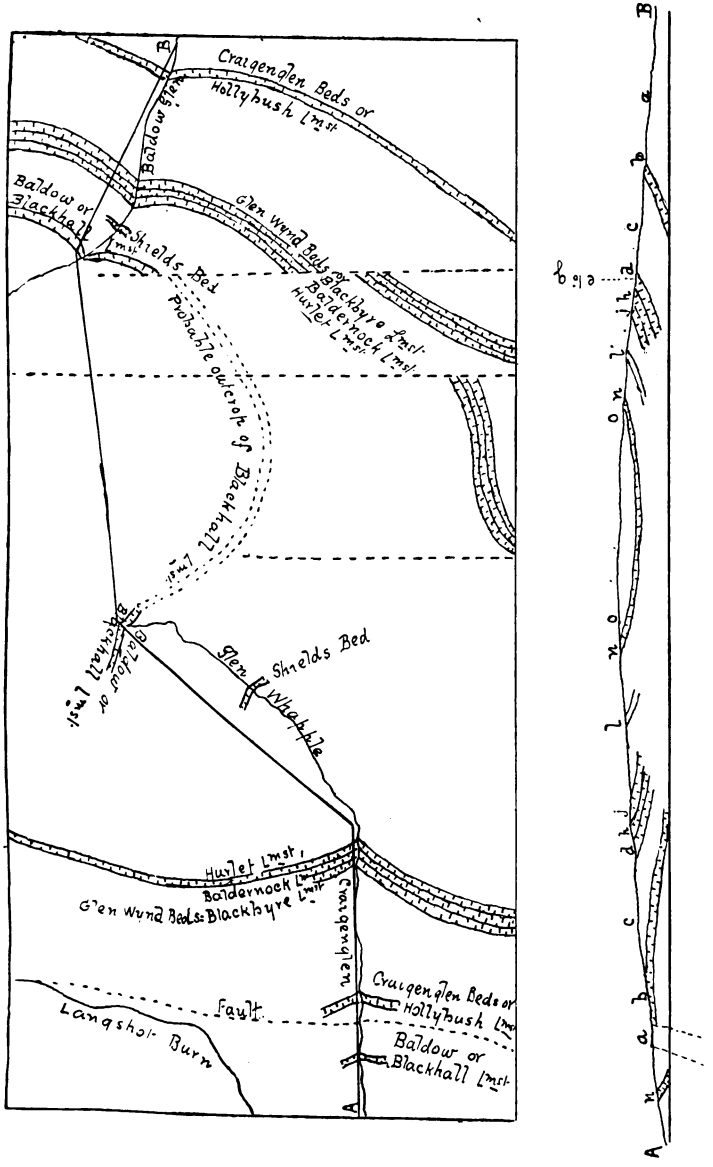

Fig 3.

Plan and section across the South Hill of Campsie from Craigenglen to Baldow Glen.

Lettering same as Table in text, see page 45.

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There can be no doubt that this represents the Blackhall Limestone with some interesting variations.

Above these strata comes a fresh series of shales with ironstones, some of which contain entomostraca and almost develop into limestone, and then we reach the two encrinital bands of the Hosie, with shale containing *Posidonomya corrugata*[6] (marked *i* in section).

We consider that the Nethercraigs, Howood, and Gryfe sections together afford important evidence bearing upon the co-relation of the Hurlet section with those in the north of Ayrshire. Thus it seems to us that the lower division of the main limestone, as seen at Broadstone, Beith, and elsewhere, with its underlying coal is the equivalent of the Hollybush seen in the three Renfrewshire localities. The fragmental deposits lying between the lower and upper divisions of the main limestone of Ayrshire, as seen at Broadstone, is the representative of the Hollybush Sandstone; while the upper division of the main limestone, as seen at Dockra, is the equivalent of the Blackbyre Limestone, the position of this limestone being fixed over a large part of the north of Ayrshire by the capping of ashy muds with limey nodules, which, we have shown, is so characteristic of this horizon in the Renfrewshire sections. The Hurlet in the north of Ayrshire has dwindled to less than its thickness in the type section, and the top of the Lower Limestone Series is marked by beds of limey shale with *Posidonomya corrugata*, which have a very striking resemblance to the shales and limestones of Calderwood Glen. We hope, however, to deal with this matter in more detail next session.

Crossing now to the north side of the Clyde, we take the Campsie district first, because there we find the clearest sections. There are no sections so complete as that on the Gryfe, but, in the numerous small burns, exposures occur which can be pieced together. In the Memoir it is stated that the Hollybush Limestone is not seen north of the Clyde, but we

[6] See *Trans. Geol. Soc. Glas.*, vol. xiv., part iii., page 309, "On the Distribution of *Posidonomya corrugata*, Ether. Jun., in the Carboniferous Limestone of the Glasgow District," by Peter Macnair, F.R.S.E., F.G.S., and Harry R. J. Conacher.

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believe its exposures there are more plentiful than those of any other beds.

South Brae of Campsie.—In Craigen Glen there is a section of a series of shales which are famous for the variety of their fossils. These beds are correlated by the Survey with the Blackbyre Seam (Productus Shales), but we are of opinion that they represent the Hollybush horizon. The section, beginning at the base, shows an oolite in fireclay-like beds overlain by sandstone containing a thin coal. The limey shales contain several bands of calcareous ironstone nodules, which were formerly mined; these nodules, as well as the shales, contain producti and corals which, in some cases, have been completely removed by percolating water, leaving very striking casts of the calcareous parts of the organism. The section passes up into sandstone and fireclay apparently underlying the Hurlet, whose position is traceable, but the section at this point is obscure. In Glen Wynd, immediately to the west, the Craigen Glen shales can be identified passing under sandstone which is overlain by a limestone, consisting of beds of small producti, with plant remains, and an encrinital upper part. These characters at once suggest the Blackbyre Limestone of Barrhead, and it also has an unconformity above it, as noted at Nethercraigs. Above this unconformity is a peculiar deposit, weathering with a characteristic red crust; if sampled near its base it is found to be a hard sandstone with rootlets and spirorbis, but the upper portions are distinctly limey, and in other sections it is found to be a calmy limestone with many entomostraca. It can be examined to advantage at the Linn of Baldernock, where thin shale bands subdivide it, as is also the case elsewhere. In Glen Wynd this limestone is not well seen, and the succeeding strata are also either worked out or hidden from sight, with the exception of a black shale, baked by a sill of white trap, whose identity is betrayed by its fauna as the alum shale of Lennoxtown district. North-west of Glen Wynd a small pine wood is fronted by extensive signs of old workings, and at one point, where a small burn falls into the old waste, a few feet of an encrinital limestone, with a few small producti, is seen overlain by black shales with small ironstones. These old workings, with occasional exposures of

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the limestone, can be traced practically right round the hill, and at Boyd's Burn and Culloch Slap work is still going on. For a short distance to the south of the wood just mentioned the tirring of old opencasts encumbers the ground, but above an old mine mouth in the former bed of the stream we see again the sandy base of the Baldernock Limestone, with its line of unconformity, and it is possible to recognise below it the same beds as seen in Glen Wynd. The structure in this glen (Borraston) is complicated by a number of small faults, which repeat part of the sequence.

At Baldernock Linn, or higher in the burn which forms it, the following section is exposed:—

Black shale with small ironstone nodules.
Thin limestone, with small encrinites, &c., and pebbles of dolomite. (Shields bed).
Black shales with small ironstone nodules.
Encrinital Limestone. } Dolerite intrusion here, seen in bed
Black Shale. } of burn and in old quarry.
Coal. }
Entomostracan Limestone.
Sandy Limestone.
Unconformity.
Shales with plant remains and Lingula.
Encrinital Limestone.

This section is much distorted by the dolerite intrusion near the linn, and a small dyke and sill of white trap also appear higher up.

West of here, and near to the Auld Wives' Lifts, the sill is again seen, with fragments of limestone, &c., sufficient to identify it, and its outcrop across the slope to the south-east is marked by the depression left by old workings. No doubt this is the locality referred to in "The Geology of Campsie" where the author speaks of an encrinital limestone passing under the Craigmaddie Sandstones; in reality it is thrown against them by a fault.

Passing now to the north face of the South Brae, we get several glimpses of our encrinital limestone—sometimes accompanied by the sill—in old workings. At Culloch Slap (above Lennoxtown), where work is still going on, we see that this limestone, 4 to 5 feet thick, overlies alum shale, coal, and

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entomostracan limestone, and in Baldow Glen we see the position of these strata in the sequence. Beginning at the road to Lennox Castle, we see, in ascending order,

a Sandstones.
b Fossiliferous limey shales, with nodules and some more solid beds *Productus giganteus* (Craigen Glen beds). (Hollybush.)
c Sandstones and fire-clays.
d Limey shales crowded with small Producti and two posts of limestone composed of small encrinite fragments (Glen Wynd beds). (Blackbyre.)
e Shale with Lingula.
f Unconformity.
g Sandy Limestone.
h Entomostracan Limestone (Baldernock).
i Fireclay.
j Gap. (Campsie Main Limestone worked out.) (Hurlet.)
k Black shales with small ironstone nodules.
l Limestone band with dolomitic pebbles, encrinites, &c. (Shields bed.)
m Black shales with large C.B. ironstones at top.
n Limestone, in five beds, top one encrinital, others entomostracan and red crusted, partly oolitic, shale partings, one an oil-shale (Baldow). (Blackhall.)
o Shale with nodules (*Posidonomya becheri* bed at base).

The rest of this section shows only black shale and ironstone nodules.

It is stated by the miners that in some parts of this district there is a 14-inch coal below the entomostracan limestone (Baldernock Limestone), but we have seen no trace of this.

In the new Memoir, reference is made to a blue limestone cropping out in this glen, now no longer visible. This we suppose to be the limey shales, &c., which have yielded *Productus giganteus*. The exposure is very small and obscured by drift, but we identify it as the representative of the Craigen Glen shales, and we feel no doubt also that the productus shales with encrinital beds are the same as those seen in Glen Wynd.

The upper part of the Baldernock Limestone here contains a nodular brecciated band with rootlets, whose appearance at once suggests that already described from Thorntonhall, Gryfe, and Nethercraigs. In Baldow, the Hurlet Coal and Limestone are not seen, and the alum shale is barely visible, but all can be examined in neighbouring workings. In Culloch Slap and Boyd's Burn the alum shale contains numerous

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limestone nodules which closely resemble, when seen lying broken and weathered, the Baldernock Limestone, but they contain no entomostraca, but frequently a marine fauna, and are intricately brecciated like septarian nodules, which indeed they are. The alum shale contains a varied fauna; at Culloch Slap, Boyd's Burn, and Glen Wynd beds occur which are crowded with *Leptodomus costellatus*, while others bear only Lingula, small Producti, or *Bellerophon*, and an occasional plant print (*Sphenopteris?*), and in parts fish remains and entomostraca are abundant.[7] At Boyd's Burn and Glen Wynd, and in old bings east of Craigen Glen, we have found an occasional *Posidonomya corrugata* (one specimen from each locality).

In Baldow Glen, at the sharp bend above the Hurlet outcrop, there is well exposed the striking bed which we refer to as the "Shields Bed." This bed is seen with approximately the same features in the burn above Baldernock Linn, in diminished size in the burn at Flutcher, in the wood between Langshot and Newlands (in small burn at east side of wood), and in Glen Whapple (north-west of Upper Carlston). In the last-named locality it has become partly oolitic and sandy enough to contain annelid burrows. In the type locality (Shields Burn, Milton of Campsie), it is a 3- to 4-feet bed of sandy encrinital limestone; while it is constant in some form throughout this district, the distance above the Hurlet Limestone varies.

The section of the Baldow Limestone in Baldow Glen is the best in the district, but it is also seen in Glen Whapple, where it has been wrought, and its position is marked by old workings and numerous fine fragments at the mouth of Craigen Glen, to which position it is brought by a fault.

On the South Hill, no higher strata than the Hosie Sandstone occur, and this is to be seen in one or two small, old quarries south of Clochcore and at Newlands.

[7] In the alum shale which comes between the Cobbinshaw limestone and coal at Cobbinshaw and at West Mains there occurs an exactly similar fauna to that just described, and it is certainly very striking that in two places so widely separated there should be found such a close resemblance in the strata and their contents; in both districts the descending sequence is encrinital limestone, alum shale, pyritous coal, fire-clay, and entomostracan limestone.

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North Brae of Campsie, &c.—Leaving the South Hill and crossing to Balgrochan, north of Lennoxtown, we find 4 to 5 feet of encrinital limestone capped by many feet of flaggy limestone, with pecten, productus, &c., and limey shales, a state of affairs similar to that at Nethercraigs, Gryfe, and Howood. Below this seam occurs the alum shale and coal, then the Baldernock Limestone, and a long section of the Glen Wynd Limestone is found in burns at Balgrochan and east of Bencloich Mains. In the burn at the latter place the Shields bed can be seen in its more typical form, and higher up the Baldow Limestone comes in. Above it at this point the shales contain an interesting fauna, not yet fully examined, including *Posidonomya becheri* (first noticed in this position by Mr. Reoch at Corrie Burn), orthoceras, and nautilus. This fauna we have also found in the same position in Baldow Glen and at Shields Cottage, but where the limestone crops in Glen Whapple the shales are too much crushed by an adjacent fault to yield fossils. The Baldow Limestone is also exposed in the Bught Glen at Maiden Castle, where it is curious to note that the burn has sunk its ravine many feet right through that structure.

In the burn east of Shields Farm we get our first sight of the Hosie Limestone, where it is of a cement-like nature in two bands about 8 feet apart, accompanied by black shales and one or two ironstone and kingle ribs. A few feet above the upper limestone the *Posidonomya corrugata* beds occur in good form. The group is not again seen clearly until we reach the Corrie district, but there the burn west of Burnhead gives an excellent section.

Above the Hosie Limestone along the south face of the Campsie Hills between Corrie and Spouthead there occurs a mass of sandstone alternating with shales and fakes, the alternation being repeated several times with remarkable regularity. Near the top of the series there occurs a sandstone with annelid burrows and *Spirophyton caudagalli* and small encrinities, and the latter bed is also to be seen near Burnhead.

At Corrieburn there is a very interesting section, which passes from the zone of the volcanic detritus, with rough conglomerates and fine muds to the strata above the Upper

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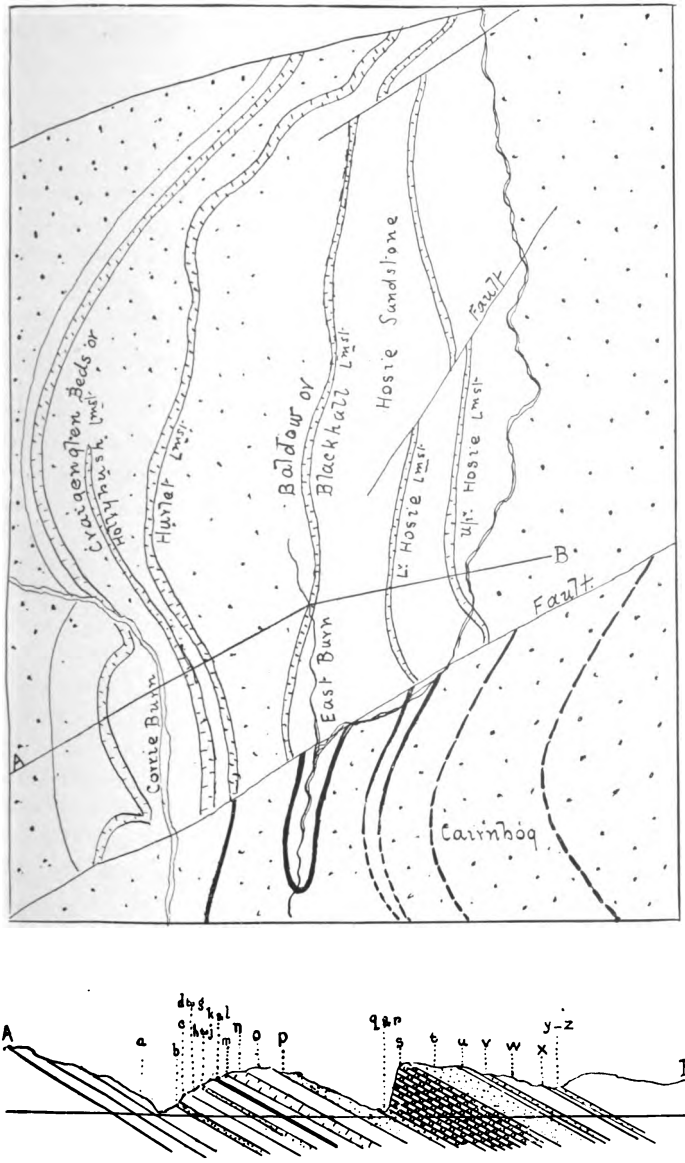

Fig. 4.

Plan and section across Limestones at Corrieburn, Kilsyth.
Lettering same as Table in text, see page 49.

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Hosie Limestone. The details of the section as observed by us differ from those given in the Survey Memoir, and we set them out side by side below—

Survey Memoir.	*Present Authors.*
Black oily shale with *Lingula*.	*z* *Posidonomya corrugata* beds and *Lingula* shale.
Limestone with *Bellerophon* (Hosie Limestone).	*y* Black limestone with *Bellerophon*.
Strata with thick yellow sandstone (Hosie Sandstone).	*x* Black shales with *Leptodomus costellatus*, *Pinna*, &c.
Black shale with septarian ironstone nodules. Marine fossils near base.	*w* Limey shale.
Limestone, partly marine with encrinites, partly dolomitic and oolitic with entomostraca (Blackhall).	*v* Black limestone with *Bellerophon* and *Orthoceras*.
Strata—black shales and sandstones with I.S. band.	*u* Shale.
Hurlet Limestone. { Upper hard band. Calmy band. Lower hard band.	*t* Sandstone.
Large growth forms of brachiopods and mollusca.	*s* Shale with nodules (*P. becheri* bed at base).
Strata with thin coal.	*r* Encrinital limestone with small solitary corals.
Coral limestone.	*q* Brown-crusted entomostracan limestone.
Black shales, sandstone bands, ironstones and calcareous nodules; with alternations of purplish volcanic detritus and rolled fragments. *Lingula* in shales and volcanic muds.	*p* Sandstone, flaggy and ripple-marked, limey and oolitic in parts.
Thick volcanic muds and conglomerates resting on lavas (pp. 15 and 24 of Memoir).	*o* Limey shales with large encrinites and *Polyzoa*.
	n Encrinital limestone (Hurlet).
	m Black shale with *Leptodomus costellatus*, and small ironstone nodules.
	l Coal.
	k Fire-clay.
	j Nodular green limestone with corals.
	i Coral limestone, eroded in places (Hollybush).
	h Limey shales with *Rhynconella* and nodules containing corals and brachiopods.
	g Shale with ironstone.
	f *Naiadites crassa* bed.
	e *Sphenopteris* (?) bed.
	d Beds containing young of *Naiadites crassa*.
	c Shales grading down into volcanic mud with oolitic ironstone nodules.
	b Sandstone.
	a Muds and conglomerate.

The Hurlet Limestone appears to be correctly identified here, and the overlying beds at once betray their identity, but below the coal there is difficulty. We are inclined to think that here the line of erosion, elsewhere noted above the Glen

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Wynd Limestone, has cut out that seam, and that the coral limestone and the accompanying very fossiliferous beds are equivalent to the Craigen Glen shales.

East of Corrie there are only one or two unimportant, isolated exposures of the Baldow Limestone at Berryhill, hints of it at Linns, while the Hosie is seen at Drumnessie.

At North Bardowie, the Hurlet group can be traced by old workings, at Flutcher the Shields bed is seen, and at Dowans there is an excellent section of the Craigen Glen beds involved in a dolerite intrusion, the intervening strata being hidden.

West of Milngavie, the Hurlet group is not seen, but old workings mark its outcrop.

At Hardgate Quarry, in the burn at Duntocher Mill and at Auchentoshan and on and near the golf course at Lawmuir, are exposures of what is evidently the same calcareous series, containing corals and large producti. The character of these beds, their relation to the Hurlet outcrop, and the nature of the adjacent strata (sandstone with thin coal above and below), cause us to regard them as the equivalent of the Craigen Glen beds.

From the foregoing, it will be seen that throughout the Glasgow district the limestones are remarkably constant in occurrence, and that those modifications which take place can be traced in their development from one locality to another, showing that the Blackhall, Hurlet, Blackbyre, and Hollybush Limestones of the type locality have their counterparts north of the Clyde in the district stretching from Kilsyth to Duntocher in the Baldow, Campsie Main, Glen Wynd, and Craigen Glen beds respectively.

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Fig. 1.—Sketch Map to illustrate the Geology of the Stornoway District.

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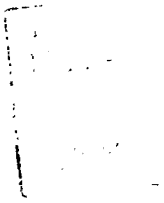

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No. VI.—Notes on the Geology of the Stornoway District of Lewis. By A. Stevens, M.A., Demonstrator in Geology in the University of Glasgow.

[Read 13th March, 1913.]

The Island of Lewis is usually described as a western outlier of the Fundamental Gneiss, but this cannot be regarded as a description in any sense, for the gneisses of Lewis present many features different from those which characterise the Lewisian of the adjacent mainland, and it is evident that they present varied phenomena of interest and importance meriting the systematic study which has so long been denied them. The earliest account of the rocks of the island is contained in Macculloch's "Western Isles" and in his letters. In both he describes the gneiss, and in the letters he figures the contortions seen in some exposures. Murchison and the Geikies have touched on the glacial and solid geology of Lewis in papers in the *Quarterly Journal of the Geological Society*,[1] and in the *Transactions of the Geological Society of Edinburgh* there is a description of the conglomerate by Morrison of Carrbridge.[2] The most recent and the most systematic examination of the gneiss was made by Drs. Peach and Horne in 1911, and their results were summarised for the Dundee meeting of the British Association of last year.[3]

The material for these notes was collected on sporadic excursions made in company with and under the guidance of Mr. W. J. Gibson, of Stornoway, and in working it up I have been indebted to Mr. Tyrrell for useful suggestions. The area studied is roughly bounded by the limits of the patch of newer sedimentaries which encircle Stornoway Harbour, and stretch northwards just past Raonadal, two miles beyond Gress (Map, Fig. 1).

[1] Murchison and A. Geikie, *Q.J.G.S.*, xvii., 1861; J. Geikie, *Q.J.G.S.*, xxxiv., 1878.

[2] *Trans., Geol. Soc., Edinburgh*, vol. v. See also chapter by the same author in Mackenzie: "History of the Long Island."

[3] Brit. Assoc. Reports, 1912.

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1. The Fundamental Gneiss.

The specimens collected by Peach and Horne have been described by J. S. Flett. He finds that biotite, biotite-hornblende, and hornblende gneisses make up most of the complex in Lewis. In the Stornoway district biotite is the most frequent ferromagnesian constituent of the rocks on the east of the town, but those on the west contain hornblende in its place, and are on the whole more basic. A typical rock from Garrabost, just east of the outcrop of the conglomerate, consists mainly of quartz and felspar in coarse square-built grains. The quartz is banded with stripes of inclusions; there is a dominant series of bands running roughly parallel to one another, and a secondary network of less conspicuous lines. Idiomorphic and rounded inclusions of quartz are frequent in the felspar and occasional in the biotite. Strain shadows (undulose extinction) are characteristic of all the quartz. The felspars are alkali-rich. Interstitial glass-clear microcline is usually present in relatively small quantity. Orthoclase is fairly abundant, and, like the plagioclase (oligoclase) has undergone sericitisation to a greater or less extent, the sericite occasionally running through the felspar in veinlets, but usually speckling the dusty crystals. The plagioclases are not infrequently bent, and the albite twin bands follow their curved outlines. It seems not unlikely that the orthoclase has been affected also by the metamorphic forces, and that the microcline structure has been set up in this mineral as a result of strain.[4] The biotite is rather sparsely distributed in these rocks. It is not, as a rule, much decomposed, but there are occasional pseudomorphs in chlorite with which are associated grains of epidote and magnetite. Fairly frequently muscovite occurs, usually in close relation with the biotite, but never in large quantity, and the gneiss passes from the first division of Teall's third group of biotite gneisses[5] to a two-mica rock of the Cabeg type.[6] The chief accessory mineral is epidote, which occurs

[4] C.p. Harker. "Petrology for Students," pp. 317, 318.

[5] Mem. Geol. Surv. "The Geology of the North-West Highlands," pp. 65-69.

[6] *Ibid.*, p. 69.

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with clinozoisite as minute crystals included in the felspar and biotite, in aggregates (saussurite), and now and then in prisms of some size. Apatite, zircon, and sphene are found, but not abundantly. The structure is granitoid, and the parallel arrangement of the mica flakes indicates the gneissic nature of the rock, a feature expressed also in the flaggy weathering of the exposed surfaces. In passing, it may be mentioned that in very large felspars obtained from similar gneiss, besides the usual quartz inclusions, numerous thin lenticles of the same mineral fill partings along the cleavage parallel to (100), and sometimes branch in the direction (010).

A couple of hundred yards east of the Garrabost margin of the conglomerate a thick dyke-like tongue of epidiorite projects almost vertically through the gneiss from a laccolith or boss of the same material. On the east side of this curved lenticles of the epidiorite run parallel to the folds of the gneiss, and appear to be phacoliths filling the crests of anticlines and the troughs of synclines, features not otherwise easily distinguished. On the opposite side of the Peninsula of Eye the cliff section shows the same dyke conspicuous against the white gneiss, together with minor apophyses and the top of the parent mass. Green hornblende makes up about half of this rock, which looks black in hand specimens. The felspar, as usual in epidiorites, is a glass-clear alkali plagioclase occurring with fairly plentiful quartz in granular crystals and as rounded inclusions in the hornblende, and, like the quartz, giving undulose extinction. Apatite is found in good-sized prisms, and a few zircons are included in the hornblende. Now and then one comes across a stray wisp of biotite.

On the west side of the town of Stornoway the hornblende gneisses which predominate are richer in ferromagnesians, and well marked with dark bands. Otherwise they are similar to the eastern types. At the east end of Loch Airidh an Eip (Vatandip) an epidote amphibolite may be seen on the sides of the new road. Associated with the hornblende, which builds two-thirds of the rock, are lobulo-reticulate masses of iron ore with specks and borders of sphene and a little chloritic material. The epidote is in small aggregates sometimes with chlorite, and is no doubt at least partly derived from decom-

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position of hornblende. A similar rock to the south of this is poorer in epidote, but contains numerous small cracked garnets.

A few hundred yards east of the point where the new Carloway road crosses the road to Callanish beyond Loch Airidh na Lic a quarry in a conspicuous black rock supplies the only tolerable road metal used in the island. This locality is easily found, for the unusually good surface of the road on either side of it at once arrests the attention of the passenger. The rock is unlike anything described from the Archæan, and suggests the ultrabasic intrusions of Old Red age, of Garabal Hill, for example, and Caithness. It is a peridotite consisting chiefly of fresh grains of olivine surrounded by serpentine and magnetite. There are large crystals of euhedral bronzite, some of which poikilitically enclose fresh olivine, and which produce an appearance of porphyritic structure. It is to be called a saxonite, but the pale yellow muscovite present recalls the scyelite of Judd, in which hornblende has replaced diallage by uralitisation. It was impossible to determine the relations of this mass of rock on account of the thick covering of peat, but it seems to be later than the gneiss and intrusive in it. On one side at least it is bounded by a very coarse acid rock containing idiomorphic felspars 1½ inches by 1 inch in section.[7] In this light-coloured material conspicuous xenoliths of the peridotite appear. Peach and Horne mention a peridotite from the Archaen complex found in the grounds of Lews Castle.

In the Stornoway area the gneiss possesses a definite foliation rendered evident by weathering in the parts where the granitoid structure and the paucity in coloured minerals make it undistinguishable in fresh hand specimens and even in the mass. The mica gneisses particularly are rather platy, and split along planes dipping steeply. The foliation planes vary in strike from north-north-east to north-west. Like the corresponding rocks of the mainland, the gneisses of Lewis weather easily, and build low moorland plateaux like those which fringe the west coasts of Sutherland and Ross where Lewisian rocks pre-

[7] This is a syenite alpite such as is associated with Old Red basic intrusions at Garabal Hill and elsewhere. Besides alkali felspar in large regular crystals with rhombic section, and quartz, it contains sphene in large brown spindles and small clear grains, brown hornblende, and biolite. Small xenoliths are represented by serpentine.

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vail. Below the soil and the thick overburden of till there is usually a deep layer of rhomboid and irregular fragments of degraded gneiss, which is the chief source of road metal in a district where it is an important consideration to find things at hand and ready made. Between the gneiss and the newer sedimentaries there is often seen a band of this material, which has been re-cemented.

2. Subsequent Metamorphism of the Gneiss.

On the shore at Gress, and again near Tolsta, bands of limestone have been mapped.[8] We have not been able to find any true limestone in the district, but on the beach at the Tolsta locality are huge blocks of a rock resembling Archæan limestone in appearance, and scratching easily on weathered surfaces, which might well be taken for that material on casual examination. The rock is *in situ* in the cliffs above, and is to be described as mylonite. It consists of fine cataclastic quartz and felspar, with unbroken grains of quartz as "eyes" in parallel arrangement. Coloured minerals are represented by stray flakes of biotite, and there are a few pieces of muscovite and some epidote (saussurite) and calcareous matter, with iron ores in fine division. Massive and flaggy representatives of the rock occur, the latter being finer in grain, and having in hand specimens of a phyllitic appearance and a soapy feel. Peach and Horne[9] state that mylonites are developed beyond the bounds of this area along the eastern seaboard from Tolsta Head to Loch Bhrollum, and associated with thrust planes tending a few degrees east of north, the direction of thrusting being, as on the mainland, towards the west. The position of this mylonite band supports these observations and deductions.

There is evidence to show that this district has been affected by extensive faulting of comparatively recent date, which has resulted in the production of alteration in bands of the gneiss as well as in the formation of a composite fault rock from gneiss and conglomerate. For instance, the cliffs at Tolsta and at Suordal present a peculiar shattered surface, and are stained

[8] Sir A. Geikie. Geol. Map, Scotland.
[9] *Loc. cit.*

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bright red with hæmatite. The rock is so brittle that it is difficult to prepare thin sections. Slides show that the quartz and felspar are smashed, and run in finely granulitic bands round quartz "eyes." In many cases these apparently unbroken quartzes are seen in polarised light to be granulitic also. The streaks of inclusions in the quartz are iron stained, the cataclastic bands are impregnated with hæmatite, and there are veins which seem to have been more open filled largely with iron ore.

Of fault rock derived wholly from the gneiss there are two kinds. The first is more basic, and perhaps was formed from epidiorite. It is seen just beyond the edge of the conglomerate at the *geodha* north-west of Raonadal, and again at Bagh Shuosdail, as a vertical band of platy rock with a chloritic feel. Felted prisms of hornblende include very subordinate dusty felspar in irregular lenticles, which are parallel to the long axis of the hornblende crystals, and a few veinlets of quartz run transverse to that direction. The other is the Lewis pebble, described as epidosite,[10] which is cut and set in silver jewellery. The beaches of Broad Bay and Bragh nah Uidhe are strewn with the pebbles, which are delicately marked with red and green, and on the shore of Mol an Droighim masses of the green material are to be seen *in situ*. The red colouration is, of course, due to hæmatite, the green to epidote. The ferromagnesian constituents of the adjacent gneiss are found to be wanting in the thin sections of the pebble, and the felspar, which is quite frequently fresh, is much reduced. Epidote, with iron ores occasionally, and with a little clinozoisite, often runs in veins with chloritic borders, penetrating even grains of quartz, sometimes ending in them. These veins now and then are cut across by tiny faults. As has been stated, the epidote of the biotite gneiss seems to have arisen in part at least from the decomposition of the biotite, and is frequently associated with the chloritic products of the change.[11] In these pebbles it is likely that under dynamic influence there has been inter-

[10] Morrison in Mackenzie: "History of the Long Island."

[11] C.p. Teall. *Loc. cit.*, p. 67. No orthite has been found in the slides examined. See also Data of Geochemistry, Bull. U.S. Geol. Surv. 491, p. 572.

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action of the felspars and the ferromagnesians with the formation of the epidote. Often the result is that a slide will show little but epidote and a few quartz crystals. These two rocks are found *in situ* close together, and the explanation of the difference between them seems to be that they were derived from gneiss bands of very different degrees of basicity, such as are frequently found in juxtaposition. It has to be remembered that in the locality the foliation planes of the gneiss are almost vertical, and so at a low inclination to the fault planes.

3. The Conglomerate.

The conglomerate series shows variation in texture from coarse breccias of sub-angular boulders of large size in a sandy matrix to incoherent micaceous sandstone. At Arnish the blocks are rough and sharp-edged, measuring up to 5 feet in diameter. At the Battery, just east of the town of Stornoway, the diameter averages about a foot, and the edges are still angular, while at Holm, Suordal, Garrabost, and Raonadal the rock is made up of more rounded stones about 4 or 5 inches each way. At Little Sandwick there outcrops on the shore a band of red ashy-looking material, which appears also on the other side of Eye, where apparently it is repeated by faulting. The outcrop of a broad band of very loose micaceous sandstone is best seen here also, and farther east a brown marl, weathering green, comes in. The series is uniformly of a chocolate colour, and this is no doubt correlated with the prevalence of iron staining in the gneiss. All the types of the conglomerate series are rich in felspar and often in biotite also, but the evidence is rather of comparatively rapid accumulation than of arid conditions. The deposits are no doubt the material of ancient sea beaches, the interstices of the coarser having been filled up with sand, and of littoral belts. On the west coast of the island away altogether from the region of conglomerate most of the beds can be paralleled in an unconsolidated condition.[12]

On the beach close to the region of the shattered gneiss

[12] C.p. Morrison, *loc. cit.*

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cliffs of Mol an Droighim, as well as at Agnish, are boulders of the same material as the less coarse-grained conglomerate, which have been indurated and cut well. They contain quartz with undulose extinction, fresh twinned felspar, and subordinate green epidote and biotite in good condition. The cement is ferruginous, but the rock has been hardened, probably at the time of the faulting, so that it rings to the hammer. This rock has not been seen in place.

In the Agnish section are numerous gentle faults which have not disturbed the uniform dip of 45 degrees towards the north-west nor the edges of the strata. Only at the head of the little bay at Roisnish, whose vertical sides are fault planes, is extensive or complex faulting to be seen, but the aggregate downthrow of the faults in the conglomerate area must be very considerable, for the high and uniform dip would otherwise give the grotesque thickness of over 3 miles for a patch of rocks which seems to be quite local and comparatively thin.

Relations and Age of the Conglomerate.—These beds have been assigned to the Torridonian,[13] to the Precambrian without reference to any particular series,[14] and to the Cambrian.[15] But the impression the loose texture of the rocks produces is that they are much younger. At every exposure of their base they are seen to rest on the Lewisian, and to have been preserved by being faulted down into it. At the inlet beyond Raonadal the fault is well seen; the gneiss on the north of the fault has been crushed, and a composite fault rock formed. The sea has excavated a cave in the fault plane by cutting out the broken edges of the conglomerate beds. At Garrabost a wedge of conglomerate has been let down just east of the main mass, which seems to be brought in by a second parallel fault, and rests on a bed of re-cemented weathered gneiss on top of the fundamental complex. J. Geikie[16] figures the beds of the sedimentaries lying similarly on the gneiss near Chicken Head.

[13] Sir A. Geikie. Geol. Map of Scotland. Teall. Geol. Map of British Isles, &c.

[14] Morrison. *Loc. cit.*

[15] Murchison and A. Geikie.; J. Geikie, *loc. cit.*

[16] *Loc. cit.*

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The material of the conglomerate is purely local, and this difference from the Torridonian[17] has struck most observers. In the coarse conglomerate on the west side of Sandwick Bay I found boulders which recalled the Torridonian of Kyle of Lochalsh (Kinloch beds, top of Diabeg group), but I do not wish to give this too much weight. These points, together with the loose texture and unaltered condition of the rocks, seem to me to put any question of Torridonian age out of court, and the Cambrian suggestion does not seem to suit the facts any better. Mr. Gibson has seen markings in the sandy beds which suggest worm tubes, and I believe Dr. Peach did find obscure worm casts. Towards Agnish I saw structures which might be such, but they were very indefinite, and, as the light thrown by worm casts on the question at issue would no doubt be vague, we must take the rocks as unfossiliferous, and depend upon lithological resemblances for an indication of their age.

Murchison and A. Geikie noted the similarity between their Lewis "Cambrian" and the mesozoic rocks of the Western Isles,[18] but, naturally enough at the time, did not pursue the comparison. Now no one can fail to mark the similarity between the Poikilitic described by Judd[19] in the Inner Hebrides and the formation under consideration. The local origin of the material, the angularity of the components, the abundance of calcareous matter, and the frequence of clayey concentrations in the finer beds, the succession, even the relation to the underlying rocks and the direction and amount of the dip urge the comparison. The probable Tertiary age of the north-west, south-east dykes which cut through gneiss and conglomerate makes the beds earlier than Eocene, and the natural conclusion, in spite of the variable value of the evidence available, is that they belong to the Trias.[20]

[17] The basal conglomerate of the lowest (Diabeg) group of the Torridonian is made up of *well rounded* Lewisian fragments.

[18] *Loc. cit.*

[19] *Q.J.G.S.*, vol. xxxiv., 1878.

[20] I believe Dr. Peach expressed a similar conclusion before this work was finished. Dr. Horne believes that these rocks are certainly not Torridonian, and Professor Judd informs me that specimens of them can be easily paralleled from the "Poikilitics" of England and of the Western Isles.

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4. North-west Dykes.

These dykes are numerous for such a small district. They have a coarse or fine-grained black basaltic appearance, and usually have baked the conglomerate on their margins. Three are seen near the western border of the conglomerate at Cuddy Point in the Castle grounds, and one of these at least appears again at Arnish. There are two on the west end of Goat Island, one on the beach at Newton, two a mile north-east from Agnish, of which one may run across to Gress, and one large dyke north of Gress, reappearing with two others in Eye, beyond our area. The thickness of these dykes varies from about a foot or 15 inches on Goat Island to 8 feet at Agnish, and more at Gress. Thin sections reveal that the material of the Stornoway dykes is the alkali basalt named crinanite by Flett, and described by him from Colonsay and Oronsay.[21] The same rock is reported from Arran by Tyrrell.[22] It differs from the basalt of the Tertiary dykes of Skye described by Harker,[23] and it is interesting to find Lewis linked up with the Small Isles by Tertiary vulcanicity also. The slides show abundant grains of olivine, fresh or in pseudomorphs, in a well-developed ophitic texture of labradorite and purple augite. Hour-glass structure and zoning are not frequent in the augite of the slides examined, but zoning is occasionally seen in the infrequent felspar phrenocrysts. Interstitial analcite and a zeolite, which has the characters of scolecite, are present in varying, often considerable, amount. But in one dyke (the most westerly of the three at Cuddy Point), where zeolite was practically absent, and analcite much reduced in quantity, the ophitic arrangement was not so well developed. Titanite with specks of leucoxene is plentiful in most slides. These dykes often stand up from the conglomerate, and even from the gneiss. They have fine-grained chilled margins, and show botryoidal weathering in varying degrees of perfection. The evidence for

[21] "The Geology of Colonsay, Oronsay, etc." Mem. Geol. Surv., 53, 1911, p. 42.

[22] *Geol. Mag.*, N.S., V., vol. x., p. 307.

[23] "Tertiary Igneous Rocks of Skye." Mem. Geol. Surv., 1904, pp. 315 *et seq.* Crinanites have since been reported from Skye; c.p., Flett, *loc. cit.*

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the Tertiary age of the dykes is their conformity with the north-west arrangement of undoubted dykes of that era elsewhere, and in a less degree their alkali affinities. But it must be remembered that on account of their peculiar nature the Tertiary age of the crinanites elsewhere has been called in question.

5. Recent Deposits.

The whole of this district is covered with till more or less thickly. Washed drift is found at Garrabost, near which are layers of shell-bearing clay, and the brick-clay unsuccessfully exploited by the late Sir James Matheson of the Lews.[24] Marine clays with foraminifera have been found in the area at considerable heights above sea-level,[25] and over all is a thick coat of peat which makes field work almost impossible except on the shore. On the sides of Broad Bay the peat banks run right to the brow of the high vertical cliffs, and, as the pools in which peat formation went on could not have extended so far the Broad Bay, must have subsided considerably in very recent times. Further, Mr. Gibson found a submerged peat bed exposed during low ebbs in Mol Sandwick (Sandwick Bay), and there is another in the little inlet at Arnish at the edge of the conglomerate. Both bear the stumps of numerous small trees, chiefly birch, and the remains of leaves may be picked up from the peat. These seem most likely to be peat banks of interglacial times,[26] but at any rate they provide further evidence regarding the subsidence which has taken place and indications of the earliest date at which it was complete.

Wind-blown sand builds the *machar* at Melbost, and similar deposits of some extent occur elsewhere in the island. The isthmus which connects the Peninsula of Eye to the main part of Lewis is formed by the coalescence of two magnificent examples of shingle bars thrown up from Broad Bay on one

[24] Morrison; J. Geikie, *loc. cit.*

[25] Robertson, *Trans., Geol. Soc., Glas.*, vol. vi., part ii.

[26] For a general and fuller account of the glaciation of Lewis, refer to J. Geikie, loc. cit., and "The Great Ice Age." For interglacial deposits, see F. J. Lewis, *Trans. Roy. Soc., Edin.*, xlvi., Part i., pp. 45-49.

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side and the Bragh nah Uidhe on the other, and ponding up between them Loch Branahuie. At Mol Sandwick and Mol Sandwick Beag there are other bars which hold up lochans, and the Teanga Thunga and the spits which run between the islets below Holm represent all stages in the formation of shingle bars. It may be mentioned that the west coast of Lewis provides a fine range of these formations; for example, that which dams Loch Mor Bharabhais and a smaller loch to the north of it.

6. Topography.

The subsidence which ended in the formation of Broad Bay may have been the same as that to which the conglomerate owes its preservation or its continuation over a period of time. In any case, there has been sinking of the Broad Bay area at a date quite recent. The cracking of the crust of the earth has here followed two directions, probably three, as the outlines of the coast shows—north-west, south-east; north-east, south-west; and east, west.[27] Possibly the cracks were not developed quite simultaneously, but submergence along one of them was possible only when the major cracks had been formed, in the north-east south-west line. The drainage system seems to be very old, for the land presents the low relief of a peneplain, and the profiles of most of the valleys show that the streams have reached their base-level of erosion. But the Creed (Fig. 2) and other streams on the

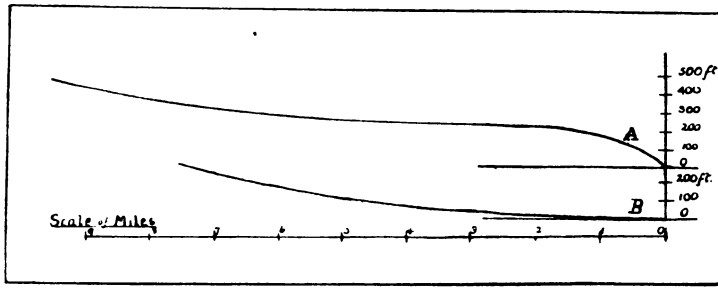

Fig. 2.—Profiles of Beds of Rivers. Creed (A) and Barvas (B).

[27] C.p., J. W. Gregory, "Nature and origin of Fiords"; map on p. 156, and pp. 171-176.

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east of the island show a break in the profile that cannot be connected with the presence of hard bands of rock. A mile from its mouth the bed of the Creed suddenly steepens, and the river seems to have been rejuvenated. This has an obvious bearing on the date of the subsidence just considered. The streams flow in long, narrow, straight valleys which have undergone extensive glaciation, and the surface of the country generally presents the subdued features typical of glaciated countries.[26] The gneiss occupies land slightly higher than that the conglomerate builds, and gives more rugged outlines: the boundaries of the latter can be quite accurately fixed on a hill-shaded map at a glance by one who has never examined the field. The view across the low ground about the town, with long hog-backed ridges planed down by the ice from the scarps of the conglomerate to the higher knobbed gneiss land, presents a memorable contrast. A feature of the coastline are the *geodhas*, narrow inlets, often with steep and lofty sides, cut by the sea along cracks and planes of weakness in gneiss and conglomerate.

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No. VII.—A Petrographical Sketch of the Carrick Hills, Ayrshire.[1]

By G. W. Tyrrell, A.R.C.Sc., F.G.S.; Lecturer in Geology, Glasgow University.

[Read 10th April, 1913.]

Introduction.

The Carrick Hills form an upland region abutting on the shore of the Firth of Clyde about 6 miles to the south-west of the town of Ayr. They consist of a series of lava flows of Old Red Sandstone age, which are exposed in a magnificent shore section and in many scarps in the interior. There are three principal areas of volcanic rocks in the district. By far the largest is that which forms the Carrick Hills proper. This area is irregular in shape, approximating to a scalene triangle, of which the coast forms one side. The longest direction of extension, E.N.E. from Dunure to a point on the Ayr-Maybole road 2 miles north-west of Dalrymple, is about 6 miles in length. The greatest breadth, from near the Heads of Ayr in a south-easterly direction, is about 2½ miles. The area covered by the lavas must be about 12 square miles.

Much smaller areas occur at Culzean and Turnberry. At Culzean the volcanic rocks are exposed in a fine mile-long cliff section, and they have a thinning, faulted extension for about a mile and a half inland towards Mochrum Hill, upon which is a small outlier of lava.

At Turnberry is another fine coastal section from Maidens to Turnberry Lighthouse, a distance of 1½ miles. The lavas are confined to a narrow strip along the shore, and any inland extension is masked by broad raised-beach deposits, which are backed by a cliff of Old Red Sandstone.

About 2 miles south of Dalrymple there are two small intercalations of lava. Both these and the Culzean and Turnberry patches must be regarded as inconstant, lenticular volcanic masses occurring at different horizons in the Old Red Sandstone.

[1] This work has been done with the aid of a Research Grant from the Carnegie Trustees for the Universities of Scotland.

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Intrusive rocks covering a considerable area, and belonging in all probability to the Old Red Sandstone igneous series, occur in the district 2 miles to the south and south-west of Maybole.

In the principal volcanic district, that of the Brown Carrick, the lavas form a moory upland, broken by lines of scarp representing the outcrops of different flows, which are separated by slaggy surfaces, or by thin, inconstant, sedimentary, or tuffaceous intercalations. The cliff and terrace topography, however, is not nearly as well developed as in the Calciferous Sandstone lavas of the Midland Valley.

I. Geological Relations.

The present paper is mostly concerned with the petrography of the Old Red Sandstone igneous rocks of the Carrick Hills, in order to correlate them with the products of the other volcanic centres of the same age in Scotland. It is intended more as a contribution to the volcanic history of Old Red Sandstone times in Scotland than as a general geological account of the district. Accordingly, the statement of geological relations here given is largely a compilation, supplemented by new facts gained in the course of the petrographical traverses.

The volcanic rocks of the Carrick Hills rest upon, and are intercalated with, a series of thick, red, yellow, and greenish sandstones, with conglomerates and cornstones, which were originally assigned by Sir A. Geikie to the Middle (?) Old Red Sandstone. This is the age given to the strata in the old 1-inch Geological Survey Map (sheet 14) and Memoir, dated 1869. The new 4 miles to the inch colour-printed map, sheet 16, Scotland (issued 1907), assigns these rocks to the Lower Old Red Sandstone, in accordance with later views, in which Murchison's "Middle Old Red Sandstone" is abandoned, leaving only the Lower and Upper divisions. The former grades conformably into the Silurian below, and the latter into the Calciferous Sandstone, with an extensive unconformity between the two divisions.[2] This unconformity is illustrated in the Carrick district by the unconformable overlap of the Upper Old Red

[2] Sir A. Geikie. "Textbook of Geology." Vol. ii. (1903), pp. 1006-1009.

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Sandstone upon both the lavas and the Lower Old Red Sandstone to the north and north-east of the area.

The bulk of the lavas in this district, those of the Brown Carrick Hills, form a platform at the top of the Lower Old Red Sandstone as it is developed in Central Ayrshire. The other smaller areas form volcanic intercalations upon several lower horizons. The intrusive rocks, however, occur in the lowermost horizons, and form thick sills running parallel with the strike of the Lower Old Red Sandstone, and of the adjacent Silurian rocks to the south.

The chief source of information upon these volcanic rocks is Sir A. Geikie's "Ancient Volcanoes of Great Britain,"[3] in which is given a full general account of their geological relations, and the Turnberry section especially is described. An earlier description is given in the Geological Survey Memoir on this district.[4] A good general account of the coast section from Ayr to Dunure is contained in a newspaper article by R. Boyle.[5] A few of the earlier paragraphs in Mr. John Smith's exhaustive monograph on the Carrick agates give the most recent description of the lavas.[6]

The most conspicuous and remarkable features of the lavas are the inclusions and intercalations of sediment they contain. Many of the fissures due to cooling, and irregular cavernous hollows, have been filled with clay and sand, giving rise to peculiar sedimentary veinings and dykes. These sediments also occur between the various flows, and now form brick-red and green mudstones, with green and red micaceous sandstones. Sir A. Geikie has figured these intercalations and inclusions from the Carrick and other Scottish districts.[7] The occurrence of the vein-like infillings in contraction-fissures and in other cavities is quite local and sporadic. The sedimentary intercalations between the flows are also thin and inconstant.

[3] Vol. i. (1898), pp. 331-335.

[4] "Memoirs of the Geological Survey of Scotland." Expl. of Sheet 14. Ayrshire, Southern District (1869), pp. 12-13.

[5] R. Boyle. "The Geology of the Coast from Ayr to Dunure." *Ardrossan and Saltcoats Herald*, March-April, 1908.

[6] J. Smith. "Semiprecious Stones of Carrick." Kilwinning. 1910, pp. 2-8.

[7] *Op. cit.* Figs. 65, 66, 76, 95, 96.; also see p. 283.

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Sir A. Geikie cites these phenomena as proving the subaqueous character of the eruptions; although in some cases he shows that the volcanic cones were built up above the surface of the water from the evidence of the coarse volcanic conglomerates occasionally intercalated between the flows, especially in Kincardineshire.[8] These conglomerates frequently contain huge blocks, often 2 feet or more in diameter, and remarkably well rounded. Sir A. Geikie regards them as the fossil representatives of shingle beaches, the constituents of which were derived partly or wholly from volcanic material.

Mr. John Smith has proposed a different explanation of the sedimentary intercalations and infillings.[9] He believes them to have been deposited in small pools of water collected on the irregular surfaces of the lava flows, and points to their inconstant character and sporadic occurrence in confirmation of this view. He has also described what he believes to be fossil markings, footprints, trailing marks of tails or spines of small animals, U-shaped tubes, spiculæ or spines, egg clusters, worm trails, and burrow markings, &c.[10] The petrological character of the infillings certainly favours this view of their origin. They are very dense red and green mudstones, and very fine-grained green and red micaceous sandstones, whose characters point to deposition in still and shallow water. They may well be derived from rain-wash into temporary pools, the mudstones representing the finest decomposed material of the lavas, and the sandstones slightly coarser sorted material. Some of the constituents, especially the numerous mica flakes, may have been brought by the wind from the arid surface of the Old Red Sandstone continent. In some cases lumps of slag occur intermingled with the sedimentary material. Moreover, many of the flows show heavy local impregnations of hæmatite, which may mark the sites of long-standing pools into which ferriferous solutions drained from the surrounding lavas. The best of these impregnations occur in the shore section to the south of the Heads of Ayr, near Carlandcheek. The hæmatite forms

[8] *Op. cit.*, p. 284.

[9] *Op. cit.*, p. 79.

[10] "The Upland Fauna of the Old Red Sandstone of Carrick." Kilwinning. 1909.

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numerous patches and veins, and in thin section the rock is seen to be largely replaced by the iron-oxide. The groundmass is often completely replaced; but the felspars remain fresh, although with infiltrations of hæmatite along their cleavages and other fissures. These areas appear to withstand marine erosion better than the unaltered lavas, and stand out in highly polished knobs above the surrounding rocks.

An exposure of conglomerate intercalated between the flows just south of the mouth of the Drumbane Burn, in a little recess of the cliff, also seems to favour Mr. Smith's views. The boulders are very numerous and are perfectly rounded. They are mostly of the size of the fist, but range up to a foot or more in diameter. The material is mainly andesite, but there are many boulders of a pale yellow felsitic or trachytic rock, and some of sandstone and shale. The matrix is composed of small angular fragments of lava embedded in a calcareous paste. This conglomerate seems to represent a torrential accumulation washed down upon the surface of a lava, and subsequently covered by a later flow. On the whole, the evidence is distinctly in favour of Mr. Smith's opinion that the lavas of the Carrick district were terrestrial and not subaqueous outpourings.

The lava cliffs of Carrick, although high and vertical, are homogeneous in aspect, and show little sign of being built of several distinct flows. In the Turnberry section, however, Sir A. Geikie has recognised thirty different sheets separated by thin sedimentary or tuffaceous layers. The flows are generally thin and impersistent, rarely reaching 50 feet in thickness. Mr. John Smith estimates the total thickness of the Carrick lavas as not more than 400 feet; but there must have been a large amount of denudation before the deposition of the unconformable overlying Upper Old Red Sandstone.

The lavas of the Carrick district lie upon different horizons, and have probably been erupted from different centres; but none of the orifices of eruption have yet been discovered. Sir A. Geikie surmises that the volcano which gave rise to the Brown Carrick Hills may be concealed somewhere under those hills. Mr. John Smith points to interbedded and water-sorted volcanic agglomerate near Dunure, in the Culzean cliff, and at Maidens Bay, as evidence of the proximity of a volcanic vent

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or vents. Mochrum Hill is largely composed of a sandy volcanic ash, but this, too, is well sorted, and owes its preservation to a cap of lava. No unquestionable volcanic vent has been discovered in this area, and it is highly probable that the vents which gave rise to the Carrick lavas are now covered by the sea.

Dykes or other intrusions connected with the lavas are extremely rare, although on the coast the lavas are cut by numerous N.W.-S.E. Tertiary dykes. One or two abrupt knolls near Dunduff Castle, about 1 mile east of Dunure, have the appearance of small intrusive bosses. These, moreover, consist of a fresh grey rock with abundant porphyritic felspar and some augite, very different in outward aspect from the amygdaloidal lavas near by.

Also just south of the top of Brown Carrick (940 feet O.D.) is a small opening showing a comparatively coarse, dark grey to black, sparingly porphyritic, and non-vesicular rock, with very advanced spheroidal weathering—an unusual phenomenon in the lavas. This appears to be a dyke, the jointing and weathering favouring this interpretation. On each side are the normal andesitic lavas.

II. The Intrusive Rocks.

On the 1-inch Geological Survey Map (sheet 14) the igneous rocks to the south and south-west of Maybole are represented as partly lavaform and partly intrusive. There can be but little doubt that all are intrusive. Petrographically the rocks are very different from the lavas. Some are dense felsite-like rocks, and others medium-grained grey dolerites, but they are all entirely devoid of the vesicular, amygdaloidal, and highly porphyritic textures characteristic of the lavas.

The intrusion nearest to Maybole, and about 2 miles south of that town, forms a thick sill-like mass, 2 miles long and ¼ mile wide, extending in a W.N.W.-E.S.E. direction. From the prominent hill occurring on part of the outcrop it may be called the Knockbrake mass. The exposures south of Glenside Reservoir consist of a hard, reddish, splintery, felsitic rock. In the quarry at the west end of the mass there is evidence

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of two distinct intrusions. The upper, forming the face of the quarry, is a pink porphyritic "felsite,"[11] the lower is a dark red, non-porphyritic felsite occurring in knobs rising through the floor of the quarry.

About a quarter of a mile south of the Knockbrae mass is Knockmill Quarry, excavated in a long, thick, dyke-like intrusion running for three-quarters of a mile in a W.N.W.-E.S.E. direction. This makes a very bold, abrupt ridge rising out of comparatively flat country. The rock is a dark felsite with a few strings and patches of pink felspathic material. The face of the quarry shows fine columnar structures bent up almost vertically at one end. In the southern part of the quarry a vertical junction with soft, white, nearly horizontal sandstone is seen. The mass therefore seems to be of the nature of a great dyke. The contact rock is excessively dense, and shows peculiar reddish and purplish blotches.

Two small dyke-like masses marked F. (felstone) and Gn. (dolerite) respectively on sheet 14 are seen near Drumbae, about half a mile S.W. of the second milestone on the Maybole-Girvan road. Both form very abrupt, bold ridges, running side by side in an E. to W. direction, with a green boggy hollow between. The so-called felstone is a dark grey compact rock, weathering pinkish, and containing a few vesicles filled with a soft, dark green mineral (celadonite). It is almost identical with the rock of the Knockbrake mass. The rock is well exposed in a quarry by the roadside. The dolerite is best seen in a crag by the roadside a little to the south of the quarry. It is a grey felspathic rock, fine grained and fresh on the margins, coarser and more decomposed in the interior. In the hollow between it and the felsite an intensely hard, glistening, vitreous black quartzite, undoubtedly a product of contact-metamorphism, is exposed in the road bottom. This occurrence proves the intrusive nature of at least one of these masses, and, as it occurs almost in juxtaposition to the felsite mass, presumably the latter was responsible for the alteration. Moreover, the intrusions are not in contact along their whole length as represented in the Survey map.

[11] 'Felsite' is here used as a convenient field term. The rock is really one of those called quartz-plagiophyres. (See p. 78).

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Almost immediately to the south of the above-described intrusions occurs a thick sill-like mass of dolerite, forming Craigfin Hill. Although the outcrop is disturbed by a small fault, the mass is continuous for 2 miles to the westward, and there forms Craigdow Hill. This intrusion forms a line of abrupt, rocky hills. There are numerous exposures near Lochspouts Reservoir, and in quarries by the roadside near Strife Knowe. The rock is a uniform, grey, felspathic dolerite, usually appearing fresh, but occasionally much weathered, with spheroidal structure.

Another large stratiform mass begins about half a mile south of Lochspouts Reservoir, and continues for about 2 miles to the W.S.W., terminating in Craigens Hill. On the ridge south of Craigdow it consists of a mass of earthy, white or yellow, banded, compact, and vesicular rhyolite or felsite. Tracing this material westward to a quarry a quarter of a mile S.W. of the summit of Craigdow, it is seen to be the upper weathered portion of a pink, quartz-bearing, felsitic rock. Towards the top of the quarry face this rock passes into the slabby, white and yellow, weathered "rhyolite."

Two miles to the W.N.W. of Craigdow Hill, and 1 mile south-west of Kirkoswald, is a thick lenticular mass of dolerite similar to that of Craigfin-Craigdow intrusion. A quarry by the roadside near Knockclog shows fine-grained dolerite apparently passing into, or involved with, a dense, splintery rock, which may be the contact-facies or a lydian stone due to the contact-metamorphism of a shale. The section is rather obscure, and does not give any decisive evidence as to the origin of the rocks.

III. Petrography.

As far as can be discovered, these rocks have never been subjected to a detailed petrographical examination. Most writers have been content to allude to them in more or less general field terms, such as "porphyrite," "felstone," "dolerite," &c. A general account of the petrography of the igneous rocks of the Old Red Sandstone in Scotland is given by

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Sir A. Geikie, and his descriptions of the andesites and "porphyrites" apply well to those of the Carrick district.[12]

The most convenient and natural classification of the igneous rocks of Carrick, which also corresponds with a petrographical classification, is into (*a*) lavaform rocks, comprising the great mass of the lavas and their attendant dykes and bosses; (*b*) intrusive rocks, representing the phase of minor intrusion, and comprising the thick, stratiform intrusions to the south and south-west of Maybole.

(*a*) *The Lavaform Rocks.*

These are overwhelmingly andesitic, and do not vary much either towards the basalts or rhyolites. Megascopically they are compact, reddish, or purplish rocks, frequently conspicuously porphyritic with felspars, but rarely so with any other mineral. They are almost invariably highly vesicular or amygdaloidal, the vesicles or amygdales being elongated in the direction of flow. The vesicles are filled with a variety of secondary products, chief among which are agates.[13] The colour of the rock may become dark, almost black, and may indicate a transition to a basaltic type, or to a rock with a large amount of glass in the groundmass. Microscopically the lavas divide up into—

I. Augite-andesite.
II. Enstatite- or hypersthene-andesite.
III. Pyroxene-andesite with olivine.
IV. Basalt.

I. *Augite-Andesite.*—The most typical rock of this group occurs on the shore near the mouth of the Ladywell Burn, three-quarters of a mile N.N.E. of Dunure. The base consists of a colourless glass so thickly charged with dark globulites as to appear almost black or dark brown when viewed with a low-power objective. In this is set an abundant generation of even-sized plagioclase felspars, euhedral, but often rendered anhedral by an invasion of glassy groundmass. Along with these are less numerous grains of a nearly colourless augite. In the

[12] "Ancient Volcanoes of Great Britain" (1897). Vol. i., p. 274.
[13] J. Smith. "Semiprecious Stones of Carrick." Kilwinning. 1910.

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above as groundmass is set an earlier generation of megaporphyritic felspars, and a few phenocrysts of augite which are largely serpentinised. The large felspars are often zonal, and carry orientated glass inclusions near their margins. The extinction angles range up to 33 degs., and indicate a composition Ab_1 An_1. The smaller felspars of the second generation are of a more acid type, giving extinctions indicating a composition Ab_5 An_3.

The proportion of felspars of the second generation to glass is estimated at 3 : 2; and that of the large felspars of the first generation to the rest of the rock as 1 : 6. The ferromagnesian constituents are quite sparse, and the dark globulitic glass doubtless contains most of the basic material.

A rock from an old quarry on the Ayr-Maybole road, 4 miles from Ayr, is generally similar to the above; but contains more abundant serpentinised augite in the groundmass, and is devoid of a megaporphyritic first generation of felspars. Another augite andesite occurs on the shore at Carlandcheek, south of the Heads of Ayr. It differs from the foregoing in having a practically holocrystalline groundmass consisting of abundant felspar laths with subordinate granular augite. Sparse megaphenocrysts of felspar give extinction angles indicating a composition Ab_4 An_5. A flow at Port Murray, near Maidens, has a holocrystalline groundmass similar to the above. It contains also diffused chloritic decomposition products, and a few fibrous pseudomorphs after an orthorhombic pyroxene. Plagioclase phenocrysts of the first generation (Ab_3 An_4) are abundant, and form perhaps one-third of the rock. This rock is also distinguished by containing a few megaphenocrysts of a pale augite with central twin-interlamellation. Another flow at Port Murray shows a comparatively coarse groundmass of fresh plagioclase and pale augite in ophitic relations, with a sparse interstitial base of dark glass. There are numerous small pseudomorphs after rhombic pyroxene, but the rock is devoid of felspar megaphenocrysts.

II. *Enstatite-Andesite.*—A most typical enstatite-andesite is a rock occurring in the cliff below Culzean Castle. It has a brown globulitic glassy base thickly sown with small, even-sized, and uniformly-distributed felspars of a second generation.

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This forms a groundmass to a first generation of large, fresh, euhedral felspars, which form perhaps one-eighth of the rock. There are also numerous smaller phenocrysts of orthorhombic pyroxene, which are invariably altered to a pale green chlorite. The shape of the pseudomorphs leaves no doubt that they represent orthorhombic pyroxene. The octagonal cross-section with dominant pinacoids and subordinate prisms is especially prominent.

The felspars of the first generation are not conspicuously zonal, but contain orientated inclusions of glass. They have a composition Ab_2 An_3 (labradorite). The small felspars of the second generation in the groundmass are highly zonal, and have an average composition of acid andesine. They are comparatively large, and generally have a short, stumpy habit. They never show well-marked fluxional arrangement. Hence the groundmass of these rocks is not typically felted or andesitic, but approaches that termed hyalopilitic. The boundaries of the felspars against the glass are frequently indefinite, and the glass emits thread-like globulitic processes into the mass of the felspar. Iron ore is sparsely but evenly distributed as minute specks throughout the groundmass. There are occasional ragged areas of hæmatite. A rock identical with this occurs on the shore a quarter of a mile north of Dunure; and a rather decomposed rock referable to this type occurs at Cross Ports, half a mile N.E. of Turnberry Castle. Variations may occur in the proportions of the large felspars of the first generation to the rest of the rock, as in the cliff under Dunure Castle, where rocks respectively almost devoid of, and extremely rich in phenocrystic felspar, occur.

III. *Pyroxene-Andesite with Olivine.*—A considerable number of the augite- and enstatite-andesites of this district contain olivine. It is never in large quantity, and is very sporadic in occurrence, tending to occur in small isolated groups, each containing a few crystals. The crystals are usually small, and verge on the microporphyritic in size. They are never fresh, but invariably altered to colourless or greenish serpentine, red lamellar iddingsite, or are replaced by hæmatite. The latter generally invests a core of serpentine or iddingsite, and has

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passed over the edges of the crystals, obscuring their usual euhedral form.

These rocks are slightly more basic than the andesites. They rarely contain a glassy base. They are richer in iron ores and granular augite, and the felspar phenocrysts of the first generation are long and narrow, whilst perfectly euhedral, and differ from the stouter crystals that occur in the andesites proper. A rock from the shore near Port Carrick, Culzean, is notable in that its felspars are decidedly more acid than those of the andesites, and give extinction angles indicating a composition near that of an acid andesine. The other rocks of this group, however, have felspars the average composition of which is medium labradorite (Ab_1 An_1—Ab_2 An_3). The types rich in augite tend also to be comparatively rich in olivine and iron ores, and pass over to the olivine-basalts. Those, however, which contain orthorhombic pyroxene remain definitely andesitic in type, and may be regarded as enstatite-olivine-andesites. Rocks of this type are met with on the shore S.W. of the Heads of Ayr, three-eighths of a mile south of Dunure Castle, in the railway cutting of the G. & S.W. Railway near the Heads of Ayr, and at John o' Groats Port in the Turnberry district. Augite-andesites with olivine occur at Port Carrick in the Culzean district, on the shore S.W. of the Heads of Ayr, and at the southern boundary of the lavas on the shore to the north of Maidens.

IV. *Basalt.*—The pyroxene-andesites pass into rocks which may be designated as basalts by an increase in the proportion of ferromagnesian silicates and iron ores. The felspar, however, does not become noticeably more basic. Olivine is invariably present, but the glassy base of the andesites has almost disappeared. Some of these rocks are undoubtedly lavaform, but others appear to form dykes and small plugs within the lavas.

A fresh lavaform type comes from near the base of the series on the shore two miles south of Dunure. In this the groundmass is composed of anhedral zonal felspar with subordinate granular pale augite, sparse and irregular iron ores, and a very small residuum of glassy matter. The rock is porphyritic, mostly with felspar of a composition Ab_1 An_1. These phenocrysts are frequently crowded with minute orientated grains of

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augite. Olivine occurs in much smaller crystals, euhedral, but completely replaced by iron ore. A rock very similar to this occurs near High Wood, $2\frac{3}{4}$ miles east of Dunure.

A rock from an apparently intrusive knoll near Dunduff Castle, 1 mile east of Dunure, differs from the above in certain particulars. There is more glass and iron ore in the groundmass. The phenocrystic felspar is more abundant, and is highly zonal. It is also much invaded and corroded by the groundmass. The olivine crystals are small, abundant, and are altered to serpentine and iddingsite, as well as replaced by iron ore. Augite occurs in large, but sparse, phenocrysts. It is euhedral, but generally corroded, and contains numerous orientated inclusions of glass, &c.

A type from a dyke south of the summit of Brown Carrick Hill carries numerous small flakes of a greenish-brown mica. The groundmass of this rock consists of anhedral felspar with abundant pale granular augite and sparse iron ore. Phenocrysts of plagioclase (Ab_2 An_3), crowded with inclusions of augite, magnetite, and glass, are abundant. There are also a few phenocrysts of augite. Olivine occurs in numerous, small, euhedral crystals completely replaced by hæmatite. The micaceous mineral has a strong cleavage, greenish-brown colour, with a pleochroism not so strong as is usual in biotites. It gives a nearly uniaxial figure of negative character, and has a double refraction approaching that of biotite. It seems therefore to be a variety of biotite. In some sections it has the appearance of being an alteration-product of orthorhombic pyroxene. The rock is classed as a mica-basalt, and, owing to the abundance of augite and olivine, is the most basic type encountered amongst the lavaform rocks.

(*b*) *The Intrusive Rocks.*

These form small sills, irregular dyke-like protrusions, and very thick, sill-like masses which cover an area of several square miles. The smaller intrusions, occurring especially to the south of Maybole, are very fine-grained, "felsitic" rocks, which, in thin section, are seen to consist mostly of a zonal plagioclase, with very subordinate ferro-magnesian

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minerals and iron ores. The texture of these rocks reminds one at once of the orthophyres, and, as the corresponding rocks consisting of plagioclase do not seem to have received a name, the term "plagiophyre" is here applied to them. They might also be regarded as leucocratic dolerites. The rocks of the great sills are dolerites, including both olivine and quartz-bearing varieties, differing only from the plagiophyres by a larger content of ferro-magnesian minerals and iron ores.

1. *Plagiophyre.*—These rocks are generally much decomposed, but have a deceptive megascopic appearance of freshness. A typical example of plagiophyre occurs in a thick, dyke-like mass at Knockmill Quarry, 2 miles S.S.W. of Maybole. The rock consists essentially of euhedral plagioclase in short laths with diverse, non-fluidal arrangement. The small interspaces are occupied by chloritic decomposition products, and the rock is uniformly sprinkled with euhedral iron oxides. A little decomposed orthoclase may occur interstitially.

The plagioclase laths which make up the great bulk of the rock are euhedral and highly zonal. Multiple twinning is not well developed. Suitable sections, however, give a maximum extinction angle of 18 degs., and, as the mineral has a refractive index greater than that of Canada Balsam, this identifies it as andesine of composition Ab_5 An_3. The marginal parts of the zonal crystals frequently give straight extinction, and are therefore to be referred to oligoclase. Untwinned felspar with a refractive index less than that of Canada Balsam occurs between the plagioclase laths, and may form an outgrowth upon them. It is clearly orthoclase, and is usually much more altered than the plagioclase felspar.

The greenish alteration products are pale bluish green in colour with a slight pleochroism, and low greyish or bluish polarisation colours. They frequently give an aggregate effect with a series of imperfect black crosses in polarised light. They are probably to be referred to a variety of chlorite. Usually they merely occupy interstitial spaces, but occasionally are found in good prismatic pseudomorphs, the terminations of which may be enclosed by felspar. These are probably after pyroxene, and the shape of the basal section shows that it was an orthorhombic variety.

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The iron ores are euhedral and usually cubic in form. They are in all stages of alteration to leucoxene, and are therefore a titaniferous variety of magnetite. A few particles of quartz occur interstitially, but these are not nearly so abundant as in the rocks described as quartz-plagiophyre below.

The texture is uniformly orthophyric, with very little trace of fluidal arrangement of the felspar laths. There are, however, a few small, irregular areas filled with a dense cryptocrystalline material containing scattered quartz grains and chlorite scales. The felspars of the rock project into these areas, which are clearly irregular cavities in the rock filled with a residual magma in much the same way as the vesicles in the Tynemouth and other dykes.

These rocks are almost identical with those termed leucophyre by German authors. Well-known examples occur at Steige, in the Vosges mountains, and Kodetz, in the Fichtelgebirge. The probably original enstatite allies them to the rocks known as enstatite diabase. The best-known British example of this type, that of Penmaenmawr, is, however, more closely related to the quartz-bearing plagiophyre described below.

2. *Quartz-Plagiophyre.*—The majority of the plagiophyre intrusions in the Maybole district are quartz-bearing. A good example comes from the roadside quarry N.W. of Craigfin Hill, 2¼ miles south of Maybole. This rock differs from the plagiophyre described above in the abundance of interstitial anhedral quartz. Orthoclase, too, is perhaps more abundant. The chlorite is extremely irregular in shape, and has probably overspread its original euhedral boundaries by migration and redeposition. Occasionally it sends processes into the felspars through the cleavage and other cracks. The felspar here has suffered much alteration, and its composition is not easy to determine. It has frequently passed into an extremely minute yellowish or pinkish dust, irresolvable even by a high-power objective. The process of decomposition is so advanced in the titaniferous iron ore that small granules of sphene have been formed.

Rocks from Kildoon Hill, 1½ miles south of Maybole, are generally similar to the rock described above, differing only in a few unessential particulars. The chlorite is a fibrous

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straight-extinguishing variety definitely pseudomorphous after enstatite. It occurs in cross-fractured prisms and in the characteristic squarish pinacoidal sections, with the corners truncated by small prism faces. A few of the felspars are so much larger than the others as to deserve the term microporphyritic. Most of the felspars give straight extinction, and therefore belong to oligoclase. There are also a few coarse-grained aggregates of plagioclase, chloritised enstatite, and iron ore, with a plutonic aspect, recalling the glomeroporphyritic groups of some basalts.

Rocks similar to the above occur also in the hilly area about Glenside Reservoir. From the floor of the quarry a quarter of a mile south-west of Glenside Reservoir comes a rock with abundant orthoclase, and this shows a perfect orthophyric texture.

The rhyolite-like rock from the quarry a quarter of a mile south-west of Craigdow appears to be a plagiophyre, very rich in quartz, but is much decomposed.

In mineralogical composition these quartz-enstatite-plagiophyres are closely related to the quartz-enstatite-diabase of Penmaenmawr. They differ, however, in texture, having a well-developed orthophyric texture in place of the close felted micrographic intergrowth of the Penmaenmawr rock.

3. *Olivine- and Quartz-Dolerite.*—The great intrusive mass of Craigfin and Craigdow Hills, and that 1 mile south-east of Kirkoswald, are composed mainly of olivine-dolerite with a quartz-dolerite facies. These are medium-grained rocks consisting essentially of plagioclase laths in ophitic relations with a decomposed pyroxene. The latter is pseudomorphed in alternating lamellæ of calcite and a strongly pleochroic, fibrous, green mineral. In other cases the pyroxene may be described as pseudomorphed by calcite, which contains anastomosing veins of the green mineral. The latter is strongly pleochroic from deep green to a yellowish green, and has rather higher double refraction than is usual for chlorite. It is positive in the direction of the fibres, and is probably a ferriferous variety of chlorite.[14] Olivine occurs, not abundantly, as easily recog-

[14] Mr. W. N. Benson informs me that this is probably bowlingite.

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nisable pseudomorphs in calcite. The iron ore occurs in irregular, clavate, skeletal forms, altering to leucoxene and occasionally sphene. The felspar is lath-shaped, zonal, with a maximum extinction angle of 30 degs., indicating a composition Ab_1 An_1 (acid labradorite). In the zonal crystals, however, a marginal zone of straight extinction indicates a transition to oligoclase. Small grains of quartz may be recognised in the interstices between the felspar laths.

The quartz-dolerite facies of the Craigfin-Craigdow mass differs from the above in the absence of olivine, the scarcity of iron ore, and the abundance of quartz. The latter occupies large interstitial areas, and is clearly original, as it envelops felspars and iron ores projecting from the walls of the areas. The felspars contain minute needles of apatite. This rock differs from the quartz-dolerites of the east-west dykes and accompanying protrusions of the Midland Valley, in the total absence of micrographic structures. An olivine-dolerite similar to that of the Craigfin-Craigdow mass also occurs at the intrusion exposed by the roadside north-west of Craigfin Hill.

IV. Petrology.

The igneous rocks of the Carrick Hills form a very compact and uniform group. The lavas are andesites which vary little from a dominant type containing orthorhombic pyroxene. Some varieties are more felspathic than the mean type; others contain more ferro-magnesian constituents, and approximate in composition to the basalts. Mineralogically the intrusive rocks are identical with the andesites, but their different habit has impressed upon them a difference of texture. They are coarser grained than the andesites, and do not possess the porphyritic and vesicular textures and glassy base so characteristic of the latter rocks. The plagiophyres are the strict hypabyssal equivalents of the andesites, and the dolerites doubtless correspond to the most basaltic types of the lavas.

Mineralogically the igneous rocks of Carrick are characterised by the predominance of plagioclase felspar, which ranges from andesine to medium labradorite, and usually constitutes an overwhelming proportion of the rock. Orthoclase is decidedly

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uncommon, but quartz is a much more abundant associate of the plagioclase. The subordinate ferro-magnesian minerals consist mainly of pyroxenes. Both iron ores and olivine are comparatively rare. The former, however, is widely distributed in small amounts; the latter is confined to two types only. Among the pyroxenes an orthorhombic variety is abundant, but is invariably altered to chlorite. This mineral association is that which characterises the so-called calcic branch of igneous rocks. The Old Red Sandstone igneous rocks of Scotland constitute a typical petrographical province belonging to the calcic branch.

Compared with the products of other centres of Old Red Sandstone igneous activity in Scotland, the Carrick suite has a very restricted petrographical range. Thus the Pentland Hills, in addition to the dominant pyroxene-andesites and associated basalts, contains trachytes (claystones) and rhyolitic lavas. Some dolerites and basalts are regarded as intrusive, and a small laccolite (Black Hill) of a red microgranite occurs.[15] A very similar association of rocks occur in the Lorne district, where basic andesites allied to basalts, hypersthene-andesites, mica, and hornblende-andesites, and felsitic lavas have been described.[16] The Cheviot Hills, according to Dr. Teall, consist of hypersthene-, augite-, and mica-andesites, which were followed by quartz-felsite dykes, and intruded by a laccolite of augite granite.[17] In the Shetlands Drs. Peach and Horne have described igneous rocks belonging to the Old Red Sandstone. These consist of porphyrites (andesites) and diabase (basalt) lavas, with dykes and bosses of diabase, dykes of rhyolite, and great intrusive sheets of two kinds of granite, and spherulitic felsite.[18] The great volcanic piles of the Sidlaw and Ochil Hills have not yet received detailed petrographical examination, but they are largely composed of andesites. Felsitic and rhyolitic lavas have been recorded; and among the intrusives are granophyric quartz-diorite (Tillicoultry), diabase, and

[15] *Mem. Geol. Sur.* "The Geology of Edinburgh" (1910), pp. 29-41.

[16] *Mem. Geol. Sur.* "The Geology of the Country near Oban and Dalmally" (1908), pp. 75-80.

[17] *Geol. Mag.* (1883), pp. 102-106, 146-152, 252-254.

[18] *Trans. Roy. Soc., Edinburgh*, vol. xxxii., part ii. (1884), pp. 259-388.

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hyperite. In the Dundee district Craig and Balsillie find that the majority of the Old Red Sandstone lavas are andesites, many of which carry hypersthene. Some, however, are more basic types. On the Fifeshire side of the Firth of Tay they find pyroxene-andesites, with felsitic lavas and dacites.[19]

In Kincardineshire Dr. R. Campbell has described the Old Red Sandstone igneous rocks as consisting mainly of hypersthene andesites, augite-andesites, and basalts, with one flow of rhyolite and two of hornblende, biotite, andesite. The hypabyssal rocks include quartz-porphry, porphyrite, lamprophyre, and dolerite.[20] The discontinuous band of Old Red Sandstone igneous rocks following the line of the boundary fault of Southern Uplands from near the Pentland Hills to beyond Dalmellington consists mainly of large intrusions of felsite (Tinto). Near Dalmellington, however, are extensive flows of pyroxene-andesite.

From this brief review it will be seen that in the great majority of the Old Red Sandstone igneous centres of Scotland the dominant pyroxene-andesites are accompanied by biotite and hornblende-andesites, and by rhyolites or felsites. The Carrick centre is singular in this respect, but in attempting to explain the deficiency of acid types it should be remembered that the rocks have suffered great denudation, and that probably a great extension of the volcanic platform is buried beneath the Firth of Clyde to the west. It is possible that were the whole of the Carrick lavas present they would be found to conform to the other areas in possessing more acid types. Some indication that acid lavas were present at some period is found in the abundance of boulders of felsite in a conglomerate intercalated between the flows (p. 68). The plagiophyre of the intrusion south of Craigdow is a type very rich in quartz, and could be described as a quartz-plagioclase-felsite. This may be regarded as an equivalent of the felsitic types of other areas.

[19] "The Geology of the Country around Dundee." British Association Handbook, Dundee, 1912, pp. 542-551.

[20] *Geol. Mag.* (V.), vol. viii. (1911), p. 69.

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Fig. 1.

Fig. 2.

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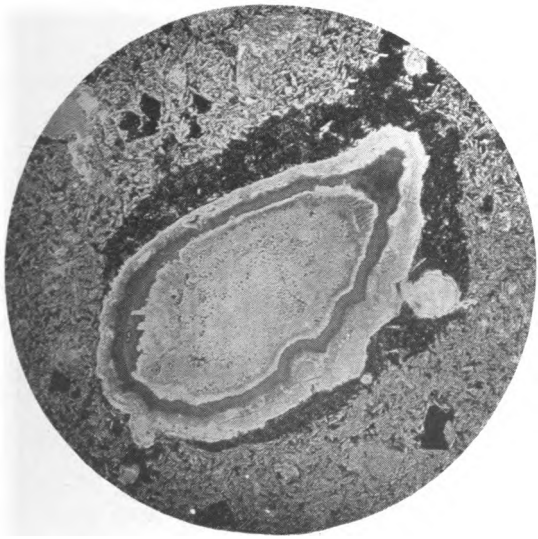

Fig 1.

Fig. 2.

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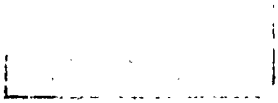

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EXPLANATION OF PLATES.

Plate VIII., Fig. 1.—Enstatite-andesite. Cliff below Culzean Castle. Ordinary light. × 24.

Shows plagioclase laths embedded in a dark glassy base. A pseudomorph in chlorite after enstatite is seen near the centre of the field. It is a basal section, and shows the rectangular pinacoidal habit of the orthorhombic pyroxenes, with the corners truncated by small prism faces.

Plate VIII., Fig. 2.—Augite-andesite with olivine. Port Carrick, Culzean. Ordinary light. × 15.

Shows a fine-textured groundmass of plagioclase laths embedded in glass, with phenocrysts of plagioclase and small euhedral crystals of olivine, which are altered to serpentine.

Plate IX., Fig. 1.—Enstatite-andesite with olivine. Carlandcheek, S.W. of the Heads of Ayr. Ordinary light. × 12.

This is a rock generally similar to the above, but shows a fissure containing an agate. The dark exterior zone is rock-glass which has infiltrated into a fissure from the surrounding rock during consolidation. This band of glassy material can be traced throughout the slide, and in some of the enlargements of the fissure agates have been formed.

Plate IX., Fig. 2.—Plagiophyre. Knockmill Quarry, two miles south of Maybole. Ordinary light. × 15.

This shows a plexus of diverse unorientated laths of plagioclase, sprinkled with iron ore and with chloritic material (turbid areas), probably representing original pyroxene, in the interspaces.

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No VIII.—Corries, with Special Reference to those of the Campsie Fells. By Professor J. W. Gregory, D.Sc., F.R.S.

[Read 8th May, 1913.]

Corries are rounded, arm-chair like, or amphitheatre-shaped depressions, with steep smooth walls and flat floors, and are situated on hillsides or beside mountain valleys. The term has, however, been used in Scotland for any rounded niche beside a valley, as by Scott in "Waverley," chapter xvi. "'This,' said Evan, 'is the pass of Bally-Brough, which was kept in former times by ten of the Clan Donnochie against a hundred of the Low Country carles. The graves of the slain are still to be seen in that little corri, or bottom, on the opposite side of the burn—if your eyes are good, you may see the green specks among the heather.'" This pass must have been at a low level, a little within the Highland border, and from the reference to the Clan Donnochie Scott probably had in mind a pass on the Tay above Dunkeld.

The term is now generally restricted to hollows well raised on the sides of mountains. The term corrie is the Scottish equivalent for the names Kar in the Bavarian Alps, Botner in Scandinavia, Oule in the Pyrenees, Cirque in the French Alps, Cwm in Wales, Coum in north-western and Coombe in southern England. Some authorities discriminate between cirques and corries. Thus Professors Penck[1] and Herbertson[2] limit the term cirques to the depressions at the heads of valleys, and apply the term corries only to those on the sides. De Martonne,[3] on the other hand, reverses this usage, for he applies the term cirques only to depressions on the sides of valleys. The restric-

[1] A. Penck. Glacial Features in the Alps. *Journ. Geol.* (Chicago) vol. xiii., 1905, pp. 15-16.

[2] A. J. Herbertson. "A Physiographical Introduction to Geography." Oxford, 1910, p. 35.

[3] E. de Martonne. "Sur la Formation des Cirques." *Ann. de Géog.*, vol. x., 1901, pp. 10-16; and "Fjords, Cirques, Vallées Alpines, et Lacs Subalpines." *Ann. de Géog.*, vol. x., 1901, pp. 289-294.

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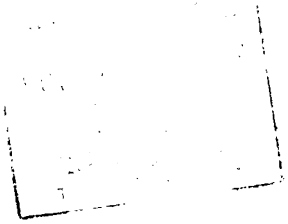

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tion of corries to hollows on the sides of valleys would be inconsistent with Scottish usage. Thus the hollow from which the village of Corrie in Arran takes its name is at the head of its valley; and that this is the normal position is suggested by the spelling, Corehead, "the head of the coire," which is quoted by Jamieson.[4] This etymology is probably of no value, as the term is derived by Skeat[5] from the Gaelic *coire*, a cauldron or kettle. Joseph Wright, in his "English Dialect Dictionary,"[6] also derives Corrie from the Gaelic for cauldron, and defines it as a circular hollow on a mountain side. The meaning of corrie for a boiling cauldron is illustrated also in the name of the whirlpool, Corrievreckan, north of the Island of Jura.

The proposed distinction between cirques and corries is, moreover, difficult to apply, since it leaves indefinite how long a valley must be before the depression at its head should be regarded as a cirque at the head of an independent valley, or as a corrie on the side of a main valley. Thus the great corrie of Ben Lui would be a corrie if regarded as a notch on the side of the valley of Allt an Lund; but it would be a cirque if considered in reference to the two streams that flow from it. The use of the terms corrie and cirque as synonymous, as adopted by Professor Bonney and others, seems therefore both etymologically correct and geographically convenient.

The Corries of Balglass.

Twelve miles due north of Glasgow on the northern face of the Campsie Fells, to the west of Fintry, there are two corries known as the Corries of Balglass (Fig. 1). The larger corrie is a magnificent amphitheatre with a regular semi-circular wall of cliffs, which are precipitous on the western side, and at their foot a steep talus bank sweeps evenly around the corrie. The corrie is about 700 feet deep, slightly under a mile wide

[4] Dr. Jamieson's Scottish Dictionary, 1841, vol. i., p. 254.
[5] W. W. Skeat. An Etymological Dictionary of the English Language, 1910, p. 137.
[6] Vol. i., 1898, pp. 735-6.

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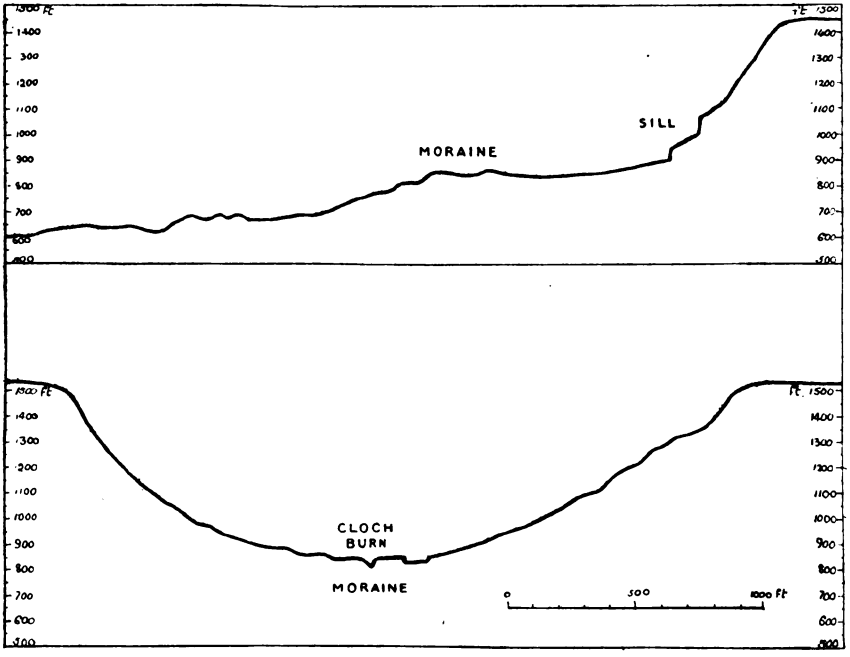
at its mouth, and nearly half a mile in length from north to south (Fig. 3). Its floor, at about 900 feet above sea-level, is



Figs. 2 and 3.

a smooth sheet of alluvium, and the burn which runs across it exposes only gravel. The mouth of the corrie is closed by a raised line of moraines, the summit of which is higher than the corrie floor within. There can be little doubt that the corrie once held a lake, which has now been destroyed by the cutting of a channel through the moraine and the filling of the basin with silt. The southern wall of the corrie is notched in one place by the rocky gulley of the Cloch burn, which rises on the fells 16 chains from the wall. Its gorge shows a clear section through the lavas and underlying tuffs. In the lower part of the wall the burn falls over a bar of Calciferous Sandstone. The rest of the rock exposed on the corrie walls belong to the Lower Carboniferous volcanic series, and include agglomerates and tuffs, basalt lavas, and a columnar sill.

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The best view of the Great Corrie is from the upper part of the Cloch burn. Thence one sees the amphitheatre, which is as perfect in form as any I remember to have seen in Scotland. The Little Corrie is less regular. It is situated to the west of the Great Corrie, the two being separated by the ridge of Barniemore, which is about a quarter of a mile wide and rises to a height of 1567 feet. The floor of the Little Corrie is at the height of slightly over 1000 feet, and its depth is about 500 feet. (Figs. 4 and 5). Its width and length may each be taken at about 2000 feet. The Little Corrie collects a larger volume

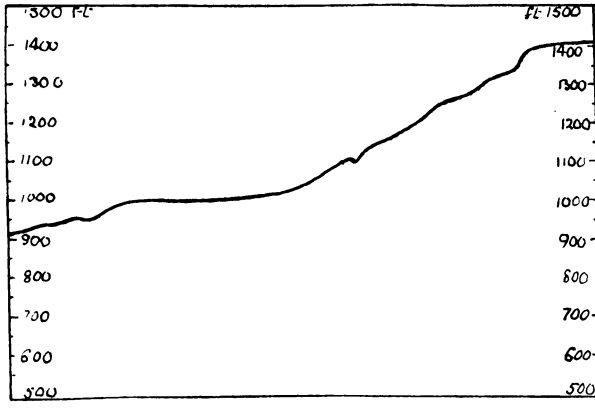

Fig. 4.

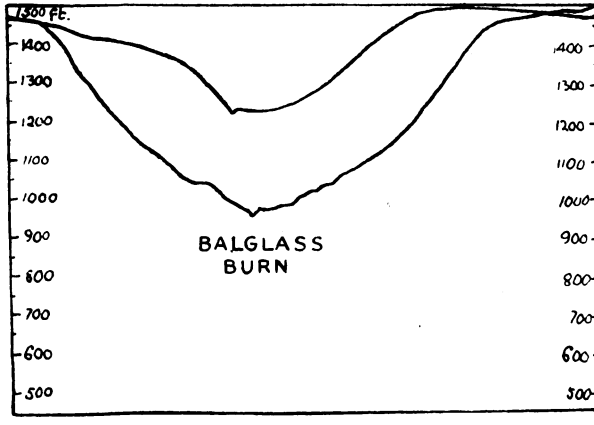

Fig. 5.

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of water than the Great Corrie, and on 12th February, 1912, seven streams and many runnels were falling over its face. The basalt sheet is thinner, its lower surface is higher above the floor than in the Great Corrie; hence all the lower part of the wall consists of sandstones and shales belonging to the Calciferous Sandstone Series; and the wearing away of these softer rocks has enabled the streams to work their way backward by undercutting the lavas. The wall is therefore more notched and the floor less regular than in the Great Corrie, which receives only one stream from the plateau. There is a small bank of red boulder clay across the mouth of the Little Corrie, but no moraine.

The Great Corrie of Balglass may be regarded as the typical Scottish corrie, for it is probably the most perfectly developed large corrie in the Midland Valley of Scotland; it is therefore one of the most accessible, and it has been long described as a corrie in Scottish geographical literature. Thus in 1795 D. Ure, in his account of the parish of Killearn, says that the estate of Balglass "is rendered conspicuous by the *Corries* or *Curries of Balglass*. They are semi-circular excavations, naturally hollowed out in the western extremity of that ridge of hills commonly known by the name of Campsie and Strathblane Fells. Some of the corries are very spacious, being more than a mile in diameter. In several places they beautifully exhibit the various mineral strata of which the mountains are composed."[7]

There are earlier references to corries in Scottish literature, and the term is included in many old place names, such as Corrieyairack, Corrygills, Corriemulzie, &c. According to T. Henderson, the Corrie Water in Dumfriesshire owes its name to its rise in a corrie. "The Currie is a small stream, about 5 miles long from north to south, deriving its name from its source, being a *corrie*, a Celtic term, signifying a confined cleugh or glen, of which sort is the spring of the Annan, vulgarly called the 'Annan Peck,' or the Marquis of Annandale's 'Beef Stand.'"[8] This corrie, which is about 7½ miles

[7] Rev. D. Ure. Parish of Killearn. No. V. in "Statistical Account of Scotland," vol. xvi., 1795, p. 104.

[8] Rev. T. Henderson. Parish of Drysdale. No. xxviii. in "Statistical Account of Scotland," vol. ix., 1793, p. 419.

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north-east of Lockerbie, is exceptional in that it faces south of south-west, and the hill shading on the engraved 1-inch Ordnance map does not represent it as a typical corrie.

Theories of the Formation of Corries.

1. *Glacial Plucking.*—The origin of corries has been much discussed, and, according to what appears to be the prevalent current opinion, they are regarded as of glacial origin, and due to the plucking of rocks from cliffs by small local glaciers during the last stage of the glaciation of a district. Their glacial origin is maintained by Helland, Von Richthofen, Reusch, de Lapparent, I. C. Russell, Maxwell Close, W. D. Johnson, G. K. Gilbert, W. M. Davis, de Martonne, Hobbs, Harker, E. C. Andrews, &c.[9]

A variation of the glacial theory was suggested by Goodchild[10] to explain the corries on the sides of valleys. He described them as gigantic potholes which had lost one side, and were due to the eddying of ice around the curves in the valleys.

The original glacial theory assigned corries to ordinary glacial abrasion, but this view was attended by the difficulty that corries are best developed along the upper edge of former snow fields and ice fields; they therefore occur where the glacier was weakest, had the purest ice, and the least erosive power. It has been pointed out, moreover, that, where the ice is thick and is abundantly armed with abrading material, it destroys corries, as it wears away all projecting rocks and ridges, and rounds off all sharp angles and edges. Accordingly, de Martonne insists that the passage of an ice sheet would inevitably destroy any pre-existing corries; he regards them as formed by small valley glaciers of the type present in the Pyrenees. In the papers already cited he attributes corries therefore to a special or Pyrenean type of glaciation.

To obviate this difficulty the advocates of the glacial theory generally attribute the formation of these steep rock walls to

[9] The glacial theory is criticised and many references to the earlier literature given in H. H. Howorth's "Glacial Nightmare and the Flood," vol. ii., 1893, pp. 615-622.

[10] J. G. Goodchild. On the Origin of Coums. *Geol. Mag.*, Dec. 2, vol. ii., 1875, p. 496.

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the cutting backward of the lower face by plucking. This process was originally described by Le Conte in 1875 as "rough-hewing";[11] it was independently invoked by Lorange, an officer in the Royal Norwegian Engineers, whose views are given by Helland.[12] He states that around Justedalsbraen, beneath the glaciers in the cirque, Lorange "saw a great many stones, some of which, sticking fast in the glacier, were quite lifted up from the bed of the cirque, while others were touching or resting on it." According to his account, the shattering of the rocks is due to frost, and the glacier pulls out and removes the loosened blocks.

Russell, in his classical essay on the "Quaternary History of Mono Valley, California," described many cirques in the High Sierra,[13] some of which open northward, while others face southward. He accepted their glacial origin, and explained the contrast between their rough walls and smooth floors by the ice exerting its full weight and abrading power only upon its floor. "The blocks, loosened from the walls of the cirque, are carried away by the outward flow of the ice."[14]

The present widespread faith in glacial plucking as an important part of glacial erosion is mainly due to the paper by Professor W. D. Johnson in 1904.[15] He had called attention to its importance in 1899, as sapping, whose action is horizontal and backward";[16] and he pointed out that, while ordinary glacial scour produces sweeping curves, sapping forms cliffs and benches. But in the same year, in another paper, he stated with the utmost clearness that this sapping is due to sharp variations of temperature. Rocks exposed beside the edge of a sheet of ice are subject to "an alternation of freezing and

[11] J. le Conte. "On Some of the Ancient Glaciers of the Sierra Nevada." *Amer. Journ. Sci.*, 3rd Series, vol. x., 1875, p. 137.

[12] A. Helland. "On the Ice-Fjords of North Greenland, and on the Formation of Fjords, Lakes, and Cirques in Norway and Greenland." *Quart. Journ. Geol. Soc.*, vol. xxxiii., 1877, p. 164. There is a criticism of this paper by Prof. Bonney in *Geol. Mag.*, Dec. 2, vol. iv., 1877, pp. 273-277.

[13] I. C. Russell. Quarternary History of the Mono Valley, California. 8th Ann. Rep. U.S. Geol. Surv., pt. i., 1889, pp. 352-355.

[14] *Ibid.*, p. 355.

[15] W. D. Johnson. "The Profile of Maturity in Alpine Glacial Erosion." *Journ. Geol.* (Chicago), vol. xii., 1904, pp. 569-578, especially pp. 573-574.

[16] W. D. Johnson. "An Unrecognised Process in Glacial Erosion" (Abstract of Paper before Geological Society of America, Dec., 1898). Abstract in *Science*, vol. ix., 1899, p. 106.

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thawing," and the foot of the crevasse between the rock and the ice is a line of especially vigorous and sharply localised weathering. "The glacier is an agent here, directly only in the removal of waste products. Frost fracturing acts vertically downward, as well as horizontally backward, into the cliff, which it thus undercuts."[17]

2. *Confluent Waterfalls.*—The second important theory of corrie formation is that advanced by Profesor Bonney[18] in 1871. He insisted that the main hollow of a corrie is pre-glacial in age, though it has been scoured and enlarged by ice. He attributes the original hollows to the action of a series of confluent waterfalls, each of which undercuts the rocks at its foot, and thus leads to the erosion of a vertical cliff. The corries he especially described are in areas of limestones and of horizontal rocks, though he, of course, recognised their occurrence in conditions where the action of waterfalls would be less effective. This theory explains many cases, but not those where there is no collecting ground behind the corries, and where the drainage is all away from it.

3. *Meteoric Origin.*—The remaining theory attributes corries to the action of alternate frost and thaw. The earliest full statement of this theory that I have seen is that by Professor Cole in 1895 in his "Open-Air Studies," p. 56. It was independently adopted a year later by Dr. Richter for the corries of Norway,[19] and he subsequently applied it to those of the Alps.[20] Professor Cvijic[21] has adopted it for the Balkans,

[17] W. D. Johnson. "The Work of Glaciers in High Mountains." Abstract in *Science*, vol ix., 1899, pp. 112-113.

[18] T. G. Bonney. "On the Formation of 'Cirques,' and their Bearing upon Theories attributing the Excavation of Alpine Valleys mainly to the Action of Glaciers." *Quart. Journ. Geol. Soc.*, vol. xxvii., 1871, pp. 312-324; and also "On a Cirque in the Syenite Hills of Skye." *Geol. Mag.*, vol. viii., 1871, pp. 535-540. This theory is also adopted by Sir A. Geikie. "The Scenery of Scotland," 3rd edit., 1901, p. 183.

[19] E. Richter. "Geomorphologische Beobachtungen aus Norwegen." Sitz. k. k. Akad. Wiss. Wien, math. nat. Classe, vol. 105, pt. i., 1896, pp. 152-164 (see especially pp. 155, 161, 163).

[20] E. Richter. "Geomorphologische Untersuchungen in den Hochalpen." Pet. Mit., Erganzungsheft, No. 132 (vol. xxix.), 1900, pp. 4-20.

[21] J. Cvijic. "Das Rila-Gebirge und seine chemalige Vergletscherung." Zeit. Ges. Erdk. Berlin, vol. xxxiii., 1898, p. 249; L'Epoque Glaciaire dans la Péninsule des Balkans." *Ann. Geogr.*, vol. ix., 1900, p. 370. He has also described cirques in Asia Minor. Zeit. Gletscherkunde, vol. iii., 1909, pp. 28-33.

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Dr. G. F. Becker for the corries of the American Sierra Nevada, and Professor Johnson in 1899 and Professor Fairchild for corries in general.

This meteoric theory attributes corries to the shattering effect of changes of temperature near the freezing point of water. A change of a few degrees of temperature at 32 degs. F. has the maximum disruptive effect, for it freezes the water in all the cracks and joints in a mass of rock, and thus forces the blocks apart. The presence of snow and ice in a gully keeps the temperature close to the freezing point, so that the water in the cracks near the edge of the snow is frozen at night and melted during the day. In unsettled weather the freezing and thawing may take place more often than once a day. The blocks thus gradually wedged forward may be loosened and fall down the cliff or they may be torn out by avalanches; or the projecting ledges collect snow, and as it melts the water trickles behind the blocks and gives the frost the opportunity for thrusting them further forward, until the weight of snow on the widening ledge forces it from its position.

Meanwhile the floor of the corrie is protected by the ice and snow upon it.[22] A hollow not thus protected has its floor cut away by the streams that fall over the cliff, and is left as a funnel-shaped gully instead of a flat-floored corrie. In the northern hemisphere the hollows facing the south and west have suffered more from water action both during the coming and going of the glacial conditions, as the precipitation in them would be heavier and the snow would be sooner melted. Gulleys facing south-west have been attacked by larger streams, which, moreover, have been in action for a longer time than those in gulleys facing north and north-east; for as these are in shadow they may retain their carpet of snow or ice throughout most of the year, and their floors are thus protected from denudation while their walls are being cut back by frost.

Most of the higher Scottish mountains and larger valleys illustrate the striking contrast in form between the funnel-shaped gulleys and steep valleys which face south-west and the

[22] The view that the influence of the glacier in corrie formation is the removal of the fallen rocks was advocated in 1872 by O. Fisher. "On Cirques and Taluses." *Geol. Mag.*, vol. ix., 1872, pp. 10-12.

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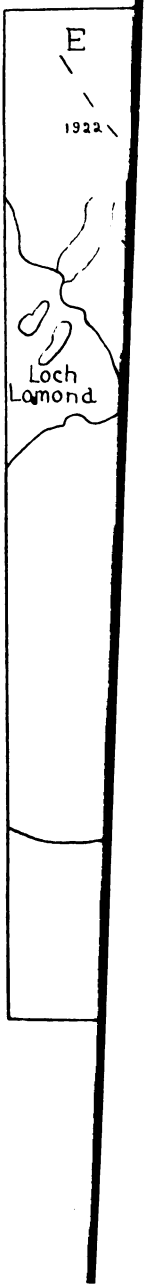

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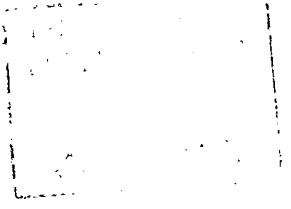

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flat-floored corries which face north-east. For instance, the corrie on the north-eastern face of Ben Lui, which can be well seen during the journey on the West Highland railway between Crianlarich and Tyndrum, is a magnificent example of a corrie, whereas a little further west the hollow on the western face of Ben Chuirn, which can be seen from the railway at "Glen Lochy Crossing," is a good example of a corrie which has been cut into a funnel-shaped valley. Along the Great Glen of Scotland there are magnificent corries on the south-western side, whereas the corresponding hollows on the north-eastern side have had their floors cut away, and are therefore funnel-shaped.

The meteoric theory explains why corries are best developed on the higher parts of mountains, on the zone which has been for a long time near the surface of the ice sheet; for there large exposures of bare rock have been in the most favourable position for disruption by frost. The origin of corries by sudden changes of temperature is also consistent with the pre-glacial age of the main depressions; for the smoothing of the walls by ice may have been most active either during the oncoming or disappearance of the glaciers; whereas on the glacial-plucking theory of corrie formation they should have been formed in the last stage of the glaciation of a district.

The presence of corries in areas that have not been glaciated is also explained by the meteoric theory. Corries have often been described, as by Professor Walther,[23] in desert regions, where they are due to the shattering of rocks by sudden contraction on the quick fall in temperature after sunset. In the tropics they generally face west, so that the rocks are heated by the afternoon sun, and rapidly chill down at nightfall. The materials that fall on the corrie floor are ground down and swept away by the wind, which is especially powerful at the foot of the cliffs, and thus keeps the walls steep and gives the corrie its semi-circular shape. The action of the daily change in temperature is also helped by the freezing of water in

[23] J. Walther. "Die Denudation in der Wüste und ihre Geologische Bedeutung." Abh. math. phys. Classe k. Sächs. Ges. Wiss., vol. xxvii., No. 3, 1891, pp. 401, 402; also A. J. Jukes-Browne. "The Origin of Cirques." *Geol. Mag.*, Dec. 2, vol. 4, 1877, pp. 477-479, for a cirque near Cairo.

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joints after storms of rain; for on mountainous deserts the temperature often falls below freezing owing to the rapid radiation through the dry air and cloudless sky. So far as I know, corries occur in the tropics only in arid areas, where, owing to the dryness of the atmosphere, changes of temperature are extreme and rapid.

The Origin of the Corries of Balglass.

It is necessary in order to understand the origin of the Balglass corries to consider a few points in the geology of the Campsie Fells. Those hills consist mainly of a basalt plateau. Their northern face is an escarpment, which now stands along a line of volcanic vents, where the southward retreat of the plateau has been checked by passage from easily denuded tuffs to hard sheets of basalt. When the Campsie plateau extended farther north the drainage flowed southward in a series of consequent rivers which discharged into the river Kelvin (Fig. 6).

The formation of the corries of Balglass began with the excavation of two valleys by the uppermost tributaries to Finglen burn. With the removal of the northern extension of the plateau and the formation of the Endrick valley obsequent streams attacked the escarpment and excavated deep gullies in it, and they are still cutting their way southward and capturing more and more of the southern drainage. As these northward flowing streams fell over the face of the plateau they undermined the basalt sheets by waterfall action, and converted the gulleys into deep semi-circular hollows. Meanwhile the Gonachan Burn had been working its way west-south-westward from Fintry along the fault, which is well shown at its western continuation near Dumfoyne. The Gonachan Burn thus diverted some of the drainage from the Finglen and carried it into the Endrick near Fintry. The divide between Gonachan Burn and Finglen Burn is now at the height of a few feet over 1500 feet, and in time the former will probably cut its way further westward through Cooper's Gate and capture the present head of Finglen Burn.

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The drainage into the Little Corrie has not yet been reduced by diversion to the north-east, and therefore has a larger collecting area and more powerful streams than the Great Corrie. It gives rises to the Balglass Burn, to which the Cloch Burn from the Great Corrie is a minor tributary.

The sketch map (Fig. 6) shows the suggested course of the drainage in the Campsie district, when the Forth had just begun to separate the volcanic plateau from the Highlands. The Campsie plateau would then have faced the north in a slight escarpment (E.E.), which extended from Ben Lomond past Ben Bhreac (1922 feet), and would have stood somewhere above the northern side of the Endrick valley. The Campsie Fells would have risen to probably 2000 feet near the northern escarpment, while the Fintry Hills probably rose to about 1700 feet and the Kilpatrick Hills to about 1400 feet. The drainage from the Campsies would then have passed south-eastward into the Glazert Water, and through it to the Kelvin, which then flowed eastward and joined the Forth. The broken lines represent the course and the arrows the directions of the rivers at this time, while the continuous lines mark the present streams.

This view of the drainage of the Campsie Fells is not quite the same as that adopted in the Geological Survey Memoir on the Glasgow District, according to which the whole of the Campsie drainage originally flowed into the Carron. The streams from the southern side of the Campsie Fells are thought to have passed into the Carron through the notch at the head of Campsie Glen. It seems to me more probable that the original drainage was south-eastward into the Kelvin, and that at first only the upper Endrick and some other streams on the Fintry Hills joined the Carron. This question does not, however, concern the origin of the corries, for Mr. E. B. Bailey in the Memoir advocates the southern recession of the northern escarpment of the Campsie Fells and the development of the corries as obsequent valleys.

Both the corries occur upon the course of old valleys, and their excavation began when the Endrick valley had reached approximately its present size. The streams in the corrie valleys had been at work for a sufficiently long time before

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the glaciation of the district to have cut deep notches into the northern face of the Campsie Fells. The original hollows were long pre-glacial. As the climate became colder the snow no doubt collected first in these sheltered hollows, as they face nearly due northward. Their sides would therefore be especially liable to attack by frost; its shattering action probably cut back the walls into steep cliffs, while the floor of the gully was protected by ice and snow. The wall of the Great Corrie gives the best evidence as to its formation, as, owing to the hardness of the material, it is better preserved. Its upper edge has been glaciated by ice travelling southward, and ice-polished rock occurs close to the foot of its cliffs; these characters and the composition of its moraine show clearly that the corrie has not been greatly extended since the country was covered by the northern ice sheet. The moraine across the entrance to the Great Corrie extends in a curved line, dying out as it mounts the slope on either side. The biggest boulders are of basalt from the corrie; but there are many blocks of schistose grit and Old Red Sandstone conglomerate, both of which must have come from the north. One boulder of schistose grit is 12 by 18 by 10 inches and another 14 by 14 by 10 inches. At two places on the moraine I estimated that one-third of the stones came from the north. Subsequently, during a visit of the geological class from the University, a third analysis of the included stones was made from material near the top of the moraine on the corrie side. The enumeration by Messrs. Scott, Walker, Stevens, Smellie, B. K. N. Wylie, and Miss Neilson gave the following results:—

	Northern Origin.	Southern Origin.
Boulders over 8 ins. diameter, - - -	7	28
Boulders between 4 ins. and 8 ins., - -	11	53
Boulders and stones less than 4 ins., - -	30	31
	48	112

Boulders of the local sandstone were excluded, as they could have come either from north or south, but there were only a few of them.

The volume of this moraine is trivial in comparison with the size of the corrie. It represents nearly the sweepings of the

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loose material in the corrie, much of which had been deposited by the northern ice. That the corrie was not formed by glacial plucking is clear, as there cannot have been any great increase in the size of the corrie after the northern ice had receded from the face of the hills; for, if so, the corrie glacier would have swept all the northern erratics out of the corrie, and the moraines would have been formed wholly of local material.

The northern ice had completely filled the corrie and overflowed to the south; it doubtless smoothed the walls and removed any weathered material. After the retreat of the main ice a small local glacier lay in the corrie and formed the small moraine. On the theory that corries have been formed by glacial plucking, the corrie would have been formed by ice flowing northward out of the corrie; but all the evidence shows that any enlargement of the corrie during or since the retreat of the main ice sheet has been insignificant. The share of ice in the formation of the corrie was exercised mainly by the corrie glacier that existed before the Campsie Fells were overridden by the northern ice, and when the young glaciers and frost were at work on a deeply weathered, decayed rock surface. That this great hollow has been formed by the glacier that deposited the moraine would appear inconceivable unless, to quote Ruskin's apt comparison, the glacier had spun around in the corrie like a "whirling Dervish."

The evidence seems to show that the meteoric theory of corrie formation best explains the origin of those at Balglass. For the corries were started as hollows by pre-glacial obsequent streams; their walls were cut back and steepened by frost action, while the floor was protected by ice and snow during the oncoming of glacial conditions; and the walls were smoothed and striated by the ice which flowed southward from the Highlands against the northern face of the Campsies. That the corries were not formed by glacial plucking during the later stages of the Ice Age is indicated by the absence of signs of plucking, the preservation of surfaces glaciated by the northern ice, and the small size of the moraines and the high proportion of northern stones in them. The majority of the Scottish corries which I have examined seem also due to the same meteoric process.

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Classification of the Scottish Corries.

Corries may be classified into three types. Typical corries are formed by the recession of their walls by frost shattering around the edge of sheets of snow and ice, while the floors are protected by a sheet of snow or a small corrie glacier. The glacier removes the material which falls from the cliffs on to its edge, and thus the junction of the snow and rock is kept always clean. The Great Corrie of Balglass is a good example of this variety.

Secondly, corries due to confluent streams which fall over hard rocks and undercut them by removal of a softer lower rock. The Little Corrie of Balglass illustrates this process; but owing to the softness of the rocks on the lower part of the walls and on the floor, the streams are now converting the corrie into a funnel-shaped valley.

Thirdly, hollows which occur on the sides of valleys, and of which the sides have been rounded and the floor scoured out by ice flowing down the valley. Goodchild called attention to this process as explaining some of the corries in the Lake District; and Glen Striddle, on the northern side of Glen Luss 2 miles from Luss Pier, which I have several times heard locally described as a corrie, is a local example of this variety.

LEGENDS OF FIGURES.

Plate X., Fig. 1.—Map of the two corries on the scale of four miles to the inch, reduced from the Six-Inch Ordnance Map by permission of the Controller General of the Stationery Office. The lines A B, C D, correspond approximately to the sections across the Great Corrie.

,, Fig. 2.—Longitudinal Section along the Great Corrie.

,, Fig. 3.—Transverse Section across the Great Corrie.

,, Fig. 4.—Longitudinal Section along the Little Corrie.

,, Fig. 5.—Also two Transverse Sections across the Little Corrie.

,, Figs. 2 to 5 are mainly due to Mr. B. K. N. Wylie.

Plate XI., Fig. 6.—Sketch Map showing the probable early drainage of the district around the Campsie Fells.

The dotted lines and dotted arrows represent the probable original course of the streams.

EE.—Former position of the Northern Escarpment.
B.—Ballagan Burn.
C.—Campsie Burn.
F.—Finglen Burn.
G.—Gonachan Burn.
Gl.—Glazart Water.
G.C.—Great Corrie.
L.—Lennoxtown.
L.C.—Little Corrie.

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No. IX.—Sweden in Glacial and Post-Glacial Time. By Dr. Horne, F.R.S.

[Delivered 10th October, 1912.]

Summary.

The main purpose of the address was to explain De Geer's method of estimating late-glacial and post-glacial time which was laid before the International Geological Congress in 1910. At the outset a brief account was given of the successive advances of the ice that radiated from Scandinavia, and of the glacial and interglacial deposits of northern Europe. Thereafter attention was directed to the investigations of De Geer, whereby he hopes to establish a chronology of the earth for the last twelve thousand years. So far, that distinguished glacialist had not published detailed descriptions of his investigations, but the members of Congress had the pleasure of listening to an address from him on the subject, and also an opportunity of examining certain sections near Stockholm, under his guidance, which indicated the nature of the evidence on which his conclusions are based.

His method of estimating late-glacial and post-glacial time is based upon certain finely laminated sediments, which were deposited during the retirement of the ice sheet and since its disappearance. In late-glacial time, when the ice shrank backwards from the Baltic coast-lands northwards to the Scandinavian ice-shed, large and small terminal moraines were laid down which indicate stages in the recession of the ice sheet. The great series of Fennoscandian moraines point to long pauses in the retreat of the ice, due to severe climatic conditions. But in other areas, as in the neighbourhood of Stockholm, there are small ridges occurring at regular intervals which, according to De Geer, mark the annual winter stages in the recession of the ice.

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The most important of the late-glacial deposits are finely stratified clays, laid down in the sea—the *Yoldia* sea of Scandinavian geologists. These clays now occupy tracts between the small terminal moraines. As the ice retired the sea advanced upon the land, and these marine deposits were slowly accumulated. The characteristic feature of these clays is the regular recurrence of a series of laminæ, varying in colour and composition, throughout extensive areas. The laminated clays and sands, according to De Geer, indicate seasonal variations, and each cycle of seasonal sedimentation is supposed to represent an annual deposition.

De Geer also found that the Swedish osar, which are well developed in the neighbourhood of Stockholm and Upsala, throw some light on the conditions of their deposition. He noted that the materials are arranged in a definite order, the coarser gravels occurring in the centre, and merging gradually into finer gravel and sand. He regards them as delta deposits, formed at the mouths of the ice tunnels as the land ice retired, and probably corresponding to the annual cycle of marine clays and the annual moraines. The materials were brought down by rivers running beneath the ice-sheet, and were discharged at the mouths of the sub-glacial tunnels as gravel, and farther out to sea as sand and clay.

From measurements of these striped clays from Scania in the south, to Jemtland in the north, he estimates that the recession of the last ice-sheet occupied a period of five thousand years. The period of retreat from Scania northwards to the limit of the Fennoscandian moraines (the goti-glacial sub-epoch of De Geer) lasted for three thousand years, while the recession from the Fennoscandian moraines backwards to the ice-shed (the fini-glacial sub-epoch) occupied about two thousand years.

The artificial drainage of Lake Ragunda, in Norrland, in 1796, furnished De Geer with data for estimating the time that has elapsed since the disappearance of the ice-sheet. There he found, resting on the floor of moraine matter, a succession of finely laminated late-glacial clays, overlain by seams of black-banded post-glacial fjord-clay. These deposits are succeeded by seasonal layers of fine sandy sediment and silt which had

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been deposited in the Lake of Ragunda since glacial time. The deposition of the finely laminated post-glacial sediments is estimated by De Geer to have extended over a period of seven thousand years.

In conclusion, reference was made to the subsequent geographical changes that converted the Baltic Sea into an inland lake, to the depression that led to the *Littorina* Sea, and to the gradual evolution of existing conditions.

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PROCEEDINGS OF THE GEOLOGICAL SOCIETY OF GLASGOW.

SESSION 1912-1913.

(Fifty-fifth Session.)

REPORT OF COUNCIL FOR 1911-1912.

The Council have again to submit their Report upon the work and events of the last session, the fifty-fifth of the Society's existence.

For some years it has been necessary to call attention to the fact that there has been considerable diminution in the roll of membership. A certain proportion of names have to be withdrawn each year owing to deaths and resignations, and the accession of new members ought to be at least as great. The Council would therefore ask members to make a stronger effort in the required direction.

As on previous occasions, your Hon. Treasurer, Mr. E. H. Wight, will submit his report upon the Financial position of the Society, and your Librarian, Mr. Wm. Sinclair, his report upon the Library.

During the bygone session many papers and notes upon specimens of interest were submitted to the Society at its meetings, which were eight in number, and which were largely attended. Among the more important papers submitted during the session were—"The Polmont Kame and on the Classification of Scottish Kames," by Professor Gregory; "Notes on the Occurrences of Chalcedony Agate and Chrystalline Quartz in the Lavas of the Campsie Hills," by Mr. J. W. Reoch; "The Garrion Gill Section at Overtown, near Wishaw," by Mr. M. Macgregor; "The Sandstones of the Upper Red Barren Measures to the East of Glasgow," by W. R. Smellie; "The Petrology of the Kilpatrick Hills, Dumbartonshire, with Notes on the Scottish Carboniferous Basalts," by Mr. G. W. Tyrrell; "Variolites from Upper Loch Fyne and Skye," by Mr. G. W. Tyrrell; "A New Theory of the Earth Geologically Considered," by Mr. W. H. Herdsman; "On the Distribution of *Posidonomya corrugata* Ether, Jun., in the Carboniferous Limestones of the Glasgow District," by Mr. Peter Macnair and Mr. Harry R. J. Conacher; "Notes on the Survey Memoir of the Geology of the Glasgow District," by Mr. James Neilson

Part 2 of volume xiv. of the *Transactions* was issued last January.

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During the summer months eleven excursions took place as follows, some of which were well attended, but others were but poorly attended:—

Baldow and Craigenglen.—Mr. H. R. J. Conacher.
Thorntonhall Quarries.—Mr. G. C. Watson.
Corrieburn.—Mr. P. Macnair.
Elie and St. Monan's, Fife.—Dr. J. Horne.
Bothwell Park Brickworks and Quarries.—Mr. W. R. Smellie.
Rumbling Bridge.—Dr. B. N. Peach.
Hurlet, Blackbyre, Hollybush.—Mr. P. Macnair.
Campbeltown.—Mr. Wm. Sinclair.
Fairy Loch, Loch Lomond.—Mr. J. W. Reoch.
Mauchline.—Mr. G. W. Tyrrell.
Garrion Burn, Wishaw.—Mr. M. Macgregor.

We have to regret the death of our much valued and esteemed member, the late Mr. John Wight, C.A., who served the Society as Hon. Treasurer for such a long period of years. We have also to regret the death of Mr. William Ker, 1 High Windsor Terrace, who became a Life Member of the Society in 1870, and, though he seldom attended the meetings, yet he was ever ready to help the Society financially. Other members deceased last year were Mr. Ronald H. Johnstone, C.E., 238 West George Street, who joined the Society in 1890, and Dr. Charles Auld, who joined in 1910.

SOCIETY'S ROOMS, 207 BATH STREET, 10TH OCTOBER, 1912.

The first meeting of the fifty-fifth Session of the Geological Society of Glasgow was held here this evening—Dr. JOHN HORNE, F.R.S., F.G.S., *President*, in the chair.

The Minutes of the last meeting were read and adopted.

The following were elected:—

As Ordinary Members—Mr. John Andrew, schoolmaster, Schoolhouse, Renton, proposed by Mr. Peter Macnair and Professor Daniel Burns; Mr. Thomas Jack, Blackhall, Brookfield, Johnstone, proposed by Mr. John Renwick and Mr. Wm. Sinclair; Mr. James Macaulay, 9 Broomhill Avenue, Partick, proposed by Mr. John Renwick and Mr. Wm. Sinclair; Mr. Harry R. J. Conacher, 51 Grant Street, proposed by Mr. Peter Macnair and Mr. George C. Watson.

Mr. G. W. TYRRELL gave notice of motion that Mr. Russell F. Gwinnell, B.Sc., F.G.S., of the Imperial College of Science and Technology, S. Kensington, London, be elected as a Corresponding Member at the next meeting of the Society. Mr. PETER MACNAIR intimated that he would have pleasure in seconding the motion.

Dr. JOHN HORNE, F.R.S., F.G.S., delivered his presidential address to the Society upon "Sweden in Glacial and Post-Glacial Times.

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Mr. JAMES STEEL, in expressing his appreciation of the address, made brief reference to the occurrence of *Yoldia* at Greenock, and to the beds with which it was associated.

Mr. JAMES NEILSON thanked Dr. HORNE for his interesting address, and asked if he could say what part of our Scottish glacial period is represented by the melting of the glaciers in Sweden. Would this correspond with the melting of our local glaciers? He did not think 12,000 or 24,000 years at all adequate to represent the period.

Mr. E. B. BAILEY also expressed his thanks. He remarked that in Scandinavia the ice-shed did not correspond with the mountain range, so that for a long time there were two mountain ranges—one of rock and one of ice—and in the valleys of the rock mountain range (now draining into the Baltic) there were great lakes, and each lake left its strand lines, the terraces of these ancient glacial lakes being just as striking and far more numerous than the parallel roads of Glen Roy. He gave an interesting account of the drainage of Lake Ragunda.

Dr. FALCONER also expressed his most hearty appreciation, and Messrs. DUNLOP and YOUNG made remarks.

Dr. HORNE, in replying, stated that in laying before the meeting the views of De Geer, he had expressed no opinion of his own. In regard to Mr. Neilson's remarks, he noticed that our conditions were widely different from those of Sweden, where as the ice retired the sea advanced. In Scotland there is no evidence of such advance. The 100 feet beach with its Arctic remains might quite well be paralleled with the *Yoldia* sea, but we have no evidence whatever that the sea advanced beyond the 100 feet beach up the valleys as the valley glaciers retired. The valley moraines were deposited on land and not beneath the sea. In reply to Mr. Dunlop, Mr. Bennie's work distinctly showed that at the bottom of the lakes in the neighbourhood of Edinburgh there is an Arctic plant horizon. That Arctic plant bed is correlated by the Swedish geologists with their Arctic plant bed that succeeded the *Yoldia* sea. In regard to the thickness of the layers in the striped clays of Sweden, these vary, some being only $\frac{1}{8}$ inch and others greater, but the total thickness of the series of deposits at Ragunda given by De Geer, where he estimates the period of 7000 years for the retirement of the ice, is only from 45 to 50 feet.

At the close the hearty thanks of the meeting were accorded to Dr. Horne.

JOHN HORNE.

SOCIETY'S ROOMS, 207 BATH STREET, 14TH NOVEMBER, 1912.

The second meeting of the fifty-fifth Session of the Geological Society of Glasgow was held here this evening—Dr. JOHN HORNE, F.R.S., F.G.S., *President*, in the chair.

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The Minutes of the last meeting were read and adopted.

The Annual Report of the Council for Session 1911-1912 was read by Mr. Peter Macnair, Hon. Secretary; the Financial Report by Mr. E. Hall Wight, Hon. Treasurer; and the Library Report by Mr. Wm. Sinclair, Hon. Librarian. These were unanimously adopted.

The following office-bearers were elected:—

As Vice-President—Mr. G. W. Tyrrell, A.R.C.Sc., F.G.S., proposed by Mr. James Steel and Mr. E. Hall Wight.

As Members of Council—Mr. John Renwick, proposed by Mr. Wm. Sinclair and Mr. Alex. M'Lean; Mr. R. W. Dron, A.M.I.C.E., proposed by Mr. J. W. Reoch and Mr. Wm. Sinclair; Dr. J. D. Falconer, M.A., F.R.S.E., F.G.S., proposed by Mr. John Renwick and Mr. G. W. Tyrrell; Mr. Wm. R. Smellie, M.A., B.Sc., proposed by Mr. G. W. Tyrrell and Mr. J. W. Reoch; Mr. Harry R. J. Conacher, proposed by Mr. Peter Macnair and Mr. E. Hall Wight—the last mentioned member of Council filling the vacancy caused by the resignation of Mr. William Lyle.

The following were elected:—

As Ordinary Members—Mr. Alexander Scott, M.A., B.Sc., 137 St. Andrew's Road, Pollokshields, proposed by Mr. Alex. Fleck and Mr. G. W. Tyrrell; Mr. Alexander Stevens, M.A., Students' Settlement, 10 Possil Road, proposed by Miss A. T. Neilson and Mr. G. W. Tyrrell.

As a Corresponding Member—Mr. Russell Frost Gwinnell, B.Sc., A.R.C.Sc., F.G.S., Imperial College of Science and Technology, S. Kensington, proposed by Mr. G. W. Tyrrell and Mr. Peter Macnair.

Mr. Peter Macnair, F.R.S.E., F.G.S., Hon. Secretary, and Mr. H. R. J. Conacher exhibited specimens of the Hurlet coal and associated limey breccia from Thorntonhall Quarries, Busby. This coal had been traced by them as a thin band occurring throughout the locality, and its occurrence here was compared with the Hurlet seam as recognised in other parts of the Glasgow district and claimed by them as being the same.

Mr. R. G. Carruthers (H.M. Geological Survey), while expressing appreciation of Mr. Macnair's stratigraphical work, gave reasons for doubting that this represented the Hurlet coal, and

Mr. James Neilson, in expressing his strong dissent, claimed that fossil evidence showed it to occur on the horizon of the Hosie Limestone.

Mr. Conacher briefly replied to these objections, and claimed that the evidence given by Mr. Macnair and himself seemed to be sufficient.

Mr. R. W. Dron, A.M.I.C.E., read a paper on "The Old Channel of the Tillon Burn, Motherwell." [See *Transactions*, p. 1.]

Mr. C. T. Clough (H.M. Geological Survey), in thanking Mr. Dron, laid emphasis on the fact that there is no evidence that this is a pre-glacial channel; but it is certainly inter-glacial. He had

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some doubt as to whether the channel at Coursington Colliery was really the old bed of the Tillon Burn.

Mr. E. M. ANDERSON (H.M. Geological Survey) had difficulty in regard to the section at the river Calder, as at this place the old channel must have been some 10 feet above the present level of the river.

Mr. G. W. TYRRELL read, on behalf of Mr. RUSSELL F. GWINNELL, B.Sc., A.R.C.Sc., F.G.S., a paper on "An Occurrence of Dolomitic Limestone in Glen Fruin." [See *Transactions*, p. 4.]

Remarks on this paper were made by Mr. CLOUGH and Mr. MACNAIR.

Mr. G. W. TYRRELL A.R.C.Sc., F.G.S., read a Report of the Proceedings of Section C (Geology) of the British Association, Dundee, 1912, at which he had acted as delegate of the Society, giving brief and interesting notices of the various meetings, excursions, and papers read.

The thanks of the meeting were heartily accorded to the several contributors.

G. W. TYRRELL.

SOCIETY'S ROOMS, 207 BATH STREET, 12TH DECEMBER, 1912.

The third meeting of the fifty-fifth Session of the Geological Society of Glasgow was held here this evening—Mr. G. W. TYRRELL, A.R.C.Sc., F.G.S., *Vice-President*, in the chair.

The Minutes of last meeting were read and adopted.

The following were elected:—

As Ordinary Members—Mr. John Smith, 1 Forbes Place, Paisley, proposed by Mr. Herbert Priestley and Mr. Duncan Smith; Mr. Percy C. Gilchrist, 532 St. Vincent Street, Glasgow, proposed by Mr. George C. Watson and Mr. Harry R. J. Conacher.

As an Associate Member—Mr. James Fraser, 169 Berkeley Street, Glasgow, proposed by Mr. William R. Smellie and Mr. J. W. Reoch.

On the motion of Mr. ARCH. A. YOUNG, seconded by Mr. JAMES STARK, Messrs. David Pearson and A. Macintyre were reappointed as auditors for the current Session.

Mr. JOHN RENWICK gave notice that he would move at next meeting "That £12 of the Society's funds be granted for Library purposes."

Mr. TYRRELL referred to the loss the Society had sustained in the death of Dr. Ramsay H. Traquair, an Hon. Member and past President of the Society, and briefly alluded to his life, work, and pre-eminence as an ichthyic palæontologist. On his proposal it was resolved that the Secretary should be instructed to send an expression of sincere regret and sympathy to his son, Mr. Ramsay Traquair.

Mr. W. H. HERDSMAN gave a summary of his "New Theory of the Earth's Structure, Geologically Considered," the discussion of which

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had been held over from last session. Various difficulties were raised by members and explanations desired.

Mr. J. G. ROBERTS, from mathematical considerations, could not accept Mr. Herdsman's postulated spherical centre of gravity. There could be no attraction inside a hollow spherical shell.

Mr. ARCH. A. YOUNG wished for an indication as to how the central void was formed in the process of cooling.

Mr. G. W. TYRRELL noted amongst other points that Mr. Herdsman's views did not seem to take into account the planetesimal theory of the origin of the earth; that it was not consonant with the accepted theory of earthquakes; that his idea of the alkali content of metamorphic and igneous rocks being an indication of the thermal metamorphism of sedimentary rocks was in opposition to facts, and was further contradicted by the recognition of petrographic provinces; that magmatic differentiation (which he understood Mr. Herdsman to deny) was accepted universally by petrologists as a fundamental of their science, and that if assimilation of neighbouring sediments is the alternative offered this has long been discredited and disproved.

Mr. HERDSMAN, in his reply, stated that even if we accepted the planetesimal theory of the earth's original solid composition, it would have assumed eventually a spherical form. Assuming the attraction of an outside body such as the moon, and that the earth's constituent particles had mobility, then by the laws of gravitation and motion alone he considered it would naturally become hollow. Mr. Tyrrell's statement as to the alkali contents of rocks was not in accord with his experience. He deferred, however, replying fully at present. But we were all working to reach the truth.

Mr. WILLIAM R. SMELLIE, B.Sc., Baxter Demonstrator in the University of Glasgow, read a paper entitled, "The Cowal 'Landslip' of 5th August, 1912." [See *Transactions*, p. 9.] The paper was illustrated by an interesting set of lantern slides.

Remarks on this paper were made by Messrs. TYRRELL, WATSON, and REOCH.

At the close a vote of thanks was accorded to the contributors.

ARCH. A. YOUNG, Chairman.

SOCIETY'S ROOMS, 207 BATH STREET, 9TH JANUARY, 1913.

The fourth meeting of the fifty-fifth Session of the Geological Society of Glasgow was held here this evening—Mr. Arch. A. YOUNG, *Vice-President*, in the chair.

The Minutes of last meeting were read and adopted.

The following were elected:—

As Associate Members—Mr. John V. Harrison, 34 Rowallan Gardens, Partick, proposed by Mr. Wm. R. Smellie and Mr. J. W. Reoch; Mr.

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A. Nicolson, M.A., 39 Stewartville Street, Partick, proposed by Mr. Wm. R. Smellie and Mr. J. W. Reoch.

Mr. JOHN RENWICK moved, in accordance with notice given at last meeting, "That £12 of the Society's funds be granted for Library purposes." This was seconded by Dr. SLOAN, and unanimously carried.

Mr. W. H. HERDSMAN replied further to the criticisms which had been made at last meeting on his "New Theory of the Earth's Structure Geologically Considered," bringing forward fuller statements in support of his position, and expressed his thanks for the time and attention which had been given to them.

Messrs. J. G. ROBERTS and G. W. TYRRELL again rejoined in expressing their dissents from certain of his conclusions, and Mr. ALEX. STEVENS also made remarks in criticism. The Chairman, in closing, moved a hearty vote of thanks to Mr. Herdsman for having given rise to an interesting discussion.

Mr. ALEXANDER SCOTT, M.A., B.Sc., read a paper entitled "The Pitchstone Dykes of South Arran." [See *Transactions*, p. 16.]

Mr. J. W. REOCH, Hon. Secretary, read a "Report of the Society's Excursion to the Fairy Loch on 22nd June last," which had been conducted at Mr. James Neilson's suggestion to investigate the cause of the bluey-green coloured patches observed on the bottom of the loch, and of the bluey-green coloured branches and twigs of trees lying waterlogged in it. It had been suggested that the colour might be due to some mineral deposit. Specimens of the twigs dragged out of the water showed a white colour on the upper half of the surface where fully exposed to light, and a dark colour on the lower half of the surface where they had been in shadow; while samples dredged from the bottom deposit showed this to be largely composed of white micas and mixed with decayed vegetable matter. The bluey-green colour was therefore thought to be caused simply by viewing these white or whitish objects through a considerable depth of very clear water, and Mr. Reoch subsequently demonstrated this to his satisfaction by sinking white objects in the water and watching them assume a bluey-green colour as they sank to the bottom. The white upper surfaces of the twigs he thought due simply to the bleaching action of light (here mainly a top light), and the patches on the bottom might be due to feeble springs, sufficient to carry away the light vegetable matter and leave clear spaces of mica sand.

The Report was discussed. Mr. JAMES NEILSON was still somewhat disinclined to accept the explanations in full. Mr. TYRRELL had no hesitation in accepting the very simple explanation given; the colour was simply the natural colour of clear water. Professor GREGORY and Messrs. YOUNG, BEGG, STEVENS, COWIE, M'LEAN, and HARRISON also made remarks, and at the close Mr. Reoch was awarded a vote of thanks.

J. HORNE.

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SOCIETY'S ROOMS, 207 BATH STREET, 13TH FEBRUARY, 1913.

The fifth meeting of the fifty-fifth Session of the Geological Society of Glasgow was held here this evening—Dr. JOHN HORNE, F.R.S., F.G.S., *President*, in the chair.

The Minutes of last meeting were read and adopted.

The PRESIDENT made brief reference to the disaster to the British Antarctic Expedition, and said it was due to the heroes who perished to give an expression of high admiration of their behaviour in the last moments of their career. He was quite certain that that document which Captain Scott penned when facing death would live as one of the noblest documents connected with Polar research. The strength of character, the iron will, the self-sacrifice, and the complete self-control were admirable. So long as our Navy was manned by men of such ideal type we as Britons might feel sure that we were perfectly secure.

Mr. HARRY R. J. CONACHER exhibited a specimen showing contortion within a coal seam from New Monkland, giving descriptive notes, and suggesting how the contortion might have been brought about.

Mr. JOHN SMITH, Hon. Member, read a paper entitled, "Carboniferous System of Scotland—East and West—a Palæontological Comparison." It is most likely that the Upper Old Red Sandstone is just the basal beds of the Carboniferous system in Scotland deposited at a time when orographic movements rendered the area a desert one; and if we do not admit this, how is it possible to account for the fact that, as soon as conditions permitted, Carboniferous species, fully developed, swarmed into the area, and had evidently been living in some congenial habitat during the time the so-called Upper Old Red Sandstone was accumulating over central Scotland, the two formations being always conformable to one another? The Ballagans, with their sparse fauna and flora, were evidently deposited in a salt lake of considerable size, the salt pseudos in the strata of the Tweed and at Ballagan itself being strong evidence of this, the few marine species found in them having evidently been cut off from the sea. The immense development of the Calciferous series in Fife compared with what it is in the West of Scotland is only partly accounted for by the space taken up by the western lava flow and ash beds; but the entire absence of the whole Calciferous series in the hills to the east of Lochleven, where the Hurlet Limestone Group rests on the Old Red Sandstone, indicates even greater differential movements in the east than in the west. During the deposition of the Calciferous strata in the east the sea made repeated encroachments into the delta area, and there were little occasional isolated areas of fresh water, such as that in which the Burdiehouse limestone was deposited, and into which marine fishes made periodic incursions, as salmon, &c., do at the present time, and also little brine lakes swarming with shrimps. The Lower Limestone Series is the most intensely marine deposit in the

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Carboniferous system of Scotland, but still not without indications of fresh water having prevailed for short periods. The inter-limestone coal series (taking the coal-bearing strata proper) is in the West of Scotland the poorest in fossils of all the series, and this is strange when there must have been immense quantities of vegetation about. The Upper Limestone Series is also intensely marine like the lower, but there were also coal-forming episodes; in fact, it is remarkable that in Scotland nearly every limestone bed or series of bands in the Carboniferous system has a coal bed a few inches or feet under it. Corals are abundant in the Lower Limestone Series and exceedingly scarce in the upper. The lower limestones are purer than the upper, and this may appear to have favoured coral growth; but the theory does not work out, as Craig's coral band, with its abundance of species, is a soft shale bed. Dr. Wheelton Hind is of opinion, backed by fossil evidence, that the Carboniferous limestone-bearing rocks of Scotland, from the base of the Calciferous to the top of the Upper Limestones, are the equivalent in time of the massive of Derbyshire (1600 feet of solid limestone), the Great Scar and Yorkshire series of Wensleydale, and the rocks in Northumberland called Carbonaceous and Calciferous by the Survey.

The Millstone Grit is a sandy, ganister, and fireclay phase in the west, more intensely sand in Fife than elsewhere, and evidently took an immense period of time to form—there having been little downward movement—so that by the time it passed away there was an all but complete change in vertebrate and plant life. During lower Coal Measure times there was a pretty steady downward movement with those occasional very strange "stand at ease" intervals when vegetation for the formation of coal beds was accumulating, and only once was it sufficiently rapid to allow the sea to get in and deposit a few inches of limestone, the great nor'-west river Carbo not being able to send any of its immense supplies of sediment into the area for a time. In the Western Islands and in Arran the coal measures are now feebly represented. During Middle Coal Measure times there was a slight alteration in plant life, and but for a bed or two of plant debris securely sealed up we would have known nothing whatever regarding the life of the Upper Coal Measures, the climatic conditions that prevailed during their deposition having evidently been quite different from those which obtained during that of the Lower Coal Measures. In the swamps there was no want of vegetation, as shown by the plant-root horizons, but it was seldom that sufficient accumulations took place to form a coal bed, the fiery heat and long dry "tids" having dissipated the greater part of the vegetation. Reading over a list of coal measure fossils a beginner might think that specimens must be abundant, but any one who watches day after day the sinking of a deep pit sees how very, very little of what had been a world teeming with life has been preserved to us. In Scotland, palæontologically speaking, there are but two great series of

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Carboniferous rocks, one below Tait's American Band (in the Millstone Grit) and the other above that band. The author's list of carboniferous fossils of the West of Scotland gives 1734 species showing the progress in discovery that has been made since 1871, when Armstrong's list gave only 676 species.

Dr. HORNE expressed his perfect pleasure in listening to this paper by such an enthusiastic worker as Mr. Smith. It was brimful of points for discussion, which he now invited.

Professor GREGORY joined in expressing his great indebtedness and gratitude to Mr. Smith for the enthusiasm and care he had given to this study. The paper demanded respectful consideration, and contained most valuable observations. Many of the points were open to differences of opinion, but it was difficult to discuss them before we had the paper in print.

Mr. JAMES NEILSON wished to echo what had been said by Dr. Horne and Professor Gregory. He did not think we had before had any paper which extends over the same reach of ground. After noticing one or two points on which he differed from Mr. Smith, he mentioned, in regard to the cornstones, that certain specimens from Millport had in the past been described in our *Transactions* as *Lithostrotion basaltiforme*. As a matter of fact it had since been found that these were not such, but simply a very calcareous conglomerate with quartz pebbles all through it which had weathered so as closely to resemble this particular coral, and he thought it might be as well now to record this.

Mr. ROBERT DUNLOP also expressed his hearty appreciation of the paper, but disagreed with some of the points.

Mr. R. G. CARRUTHERS, in thanking Mr. Smith, remarked that the paper covered a tremendous stretch of ground, and although containing many controversial points, must be of great value to students. He did not know of any paper in which you could get such a comprehensive view of the Carboniferous rocks as a whole. In regard to the cement stones he would have liked some reference to the Liddesdale and Newcastleton district, where the series is unique, containing many brachiopods, gasteropods, and small corals, and even *Lithostrotion*. He would like to emphasise the fact that the reason why the Calciferous rocks are so thin in the West of Scotland is that there is a large overlap. The Oil Shale Series was missing in the west because of an unconformity. Here he strongly dissented from Mr. Smith's views. The ash beds above the lavas were not true volcanic dust but the wash of the lavas, as had been told in the Glasgow Memoir. But, of course, Mr. Smith's was not intended to be a stratigraphical paper. Other points also were noticed. The Society were extremely fortunate in having such a paper from a man of such tremendous energy and long experience as Mr. Smith.

Dr. HORNE spoke with reference to the position of the line to be drawn between the Upper Old Red and the Carboniferous. The dis-

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covery of scales of *Holoptychius nobilissimus* in the sandstones associated with cornstones below Salisbury Crags and their neighbourhood showed without a shadow of a doubt that these were rocks of O.R.S. age, and all the evidence was distinctly against the idea that there could be any interpolations of these beds with beds containing Carboniferous fossils. In regard to the correlation of the limestones there was a difference of opinion, and he thought we would be compelled not to run a persistent Hurlet Limestone all through Scotland, but to start from local centres and take local names. He dwelt on the importance of Skipsey's band. The old notion of an unconformability in Ayrshire had been overthrown by the evidence of bores which showed that it did not exist, and that the Skipsey band was a thoroughly reliable stratigraphical zone.

G. W. TYRRELL.

SOCIETY'S ROOMS, 207 BATH STREET, 13TH MARCH, 1913.

The sixth meeting of the fifty-fifth Session of the Geological Society of Glasgow was held here this evening—Mr. G. W. TYRRELL, A.R.C.Sc., F.G.S., *Vice-President*, in the chair.

The Minutes of last meeting were read and adopted.

The following members were elected:—

As an Ordinary Member—Mr. James Grahame Walker, c/o Thomson, 4 Ann Street, Hillhead, proposed by Mr. Wm. R. Smellie and Mr. J. W. Reoch.

As an Associate Member—Mr. A. G. Keane, M.A., 1 Lothian Gardens, Cardonald, proposed by Mr. Wm. R. Smellie and Mr. J. W. Reoch.

Mr. Peter MACNAIR and Mr. HARRY R. J. CONACHER read a paper entitled, "The Stratigraphy of the Limestones lying immediately above the Calciferous Lavas in the Glasgow District." [See *Transactions*, p. 37.] Representative specimens from the different localities were exhibited.

In the discussion which followed, Mr. R. G. CARRUTHERS expressed his appreciation of the work done by the authors. In the Hurlet district he referred to the absence of field sections, and thought it desirable that a bore should be put down there to get a convincing section. As to Nethercraigs, did they find any representative of the Lady Ann Coal in the sandstone between the Blackbyre and the Holly bush Limestone? He could quite confirm the work of the Bridge of Weir section. At Campsie they had made new discoveries which had been missed by the Survey, viz., the occurrence of *Posidonomya becheri* above the Blackhall Limestone; then the Shields bed with annelids; the little unconformity on the top of the Blackbyre; and the *Leptodomus costellatus* band in the alum shale. They had also been fortunate in the discovery of a new section of interest at Howood.

Mr. JAMES NEILSON congratulated the Society on getting this paper. It was striking out anew a line of research which he thought it would

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be good for the Society not to let fall into the background. The paper represented a great deal of work. So far as Thorntonhall was concerned, he maintained all he had before said, and he thought that one or two things mentioned by the authors strengthened his position, but he was willing to take the verdict of posterity.

Mr. GEO. C. WATSON asked if the authors had found *Myalina crassa* anywhere else than at the Corrie section.

Mr. MACNAIR briefly replied. At Nethercraigs he had found signs of a coal between the Hollybush and the Blackbyre Limestone: it is only a shaly, coaly parting. The only place in the Glasgow district where he had seen the *M. crassa* bed was at Corrie, right away at the bottom. He considered the limestone at Broadstone quarries to be the Hollybush, at Dockra quarry the Blackbyre, and the thin limestone above to be the Hurlet.

Mr. ALEX. STEVENS, M.A., read a paper entitled, "Notes on the Stornoway District of Lewis." [See *Transactions*, p. 51.]

Mr. CARRUTHERS remarked that he believed Dr. Peach refers this conglomerate to the Trias. He thought that traces of annelid burrows had been discovered in them.

Mr. TYRRELL thought in regard to the conglomerate that before we ruled out the Torridonian the nature of the pebbles should be ascertained. It seemed to be possible to correlate the pebbles with those on the mainland. As to the ashbeds, he had seen the material, and it was perfectly clear to him that it was of an ash-like nature. The fragments were very angular, and included particles never got in sediments. We had here, then, a very interesting occurrence of volcanic action.

Mr. NEILSON and Mr. MACNAIR also made remarks.

Mr. STEVENS briefly replied. He did not consider the existence of annelid burrows went very far in correlating. The conglomerate looked to him like a hardened boulderclay of Archaean origin. As regards the tuff he acknowledged his indebtedness to Mr. Tyrrell for suggestions in working out his results.

A hearty vote of thanks was awarded to the contributors.

JOHN RENWICK.

SOCIETY'S ROOMS, 207 BATH STREET, 10TH APRIL, 1913.

The seventh meeting of the fifty-fifth Session of the Geological Society of Glasgow was held here this evening—Mr. JOHN RENWICK in the chair.

The Minutes of last meeting were read and adopted.

Mr. G. W. TYRRELL A.R.C.Sc., F.G.S., *Vice-President*, exhibited by lantern a fine series of geological photographs of South Arran. These included a great number of the specially interesting and beautiful features so well exposed throughout the island. The igneous intrusions of Holy Isle, King's Cross, Glen Ashdale, Dippin, Bennan,

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and Drumadoon; the splendid series of parallel and interlacing dykes to be seen on the south shore of the island; the raised beaches, boulder clay, effects of glaciation, and many other features, were well illustrated and lucidly described. A point of special interest noted by Mr. Tyrrell was the determination by him of the mineral riebeckite in the so-called felsite of Holy Isle, which he now described as a riebeckite-trachyte, and the geological relations of which were thus found to be similar to those of the rock of Ailsa Craig. A glaciated surface of this riebeckite-trachyte was illustrated, as giving a measure of the amount of erosion which had taken place since glacial times, certain silicified portions having resisted disintegration and now standing up above the other portions of the rock which had been deeply weathered.

Remarks on this exhibit were made by Mr. JAMES NEILSON and Mr. GEORGE C. WATSON. Mr. Neilson thought it might be possible to find the age of the raised beaches in Arran from their association with ancient remains, and recommended further research in this line.

Mr. TYRRELL then read a paper entitled, "A Petrographical Sketch of the Carrick Hills, Ayrshire." [See *Transactions*, p. 64.]

Mr. CONACHER expressed his interest in the finding of hæmatite in the Carrick lavas. He had noticed hæmatite occurring in boulders of lava from Renfrewshire.

Mr. TYRRELL briefly replied, and at the close was accorded a hearty vote of thanks.

J. HORNE.

SOCIETY'S ROOMS, 207 BATH STREET, 8TH MAY, 1913.

The eighth meeting of the fifty-fifth Session of the Geological Society of Glasgow was held here this evening—Dr. JOHN HORNE, F.R.S., in the chair.

The Minutes of the last meeting were read and adopted.

Mr. PETER MACNAIR exhibited on behalf of Mr. JOHN SMITH a specimen of volcanic ash containing fragments of coniferous wood from Hindog Glen, Dalry. He also exhibited a specimen of Melanterite in coal, from Quarter, near Hamilton.

Professor J. W. GREGORY, D.Sc., F.R.S., read a paper entitled "The Fiords of Dalmatia," in which he said that the conclusion that glaciers once existed in countries now free from ice and permanent snow is based on the direct evidence afforded by ice-scratched rocks and by glacial moraines, and in some indirect evidence. The latter includes a rounded surface of the land, which is often described as a subdued relief; large areas of bare, fresh rock, owing to the material which has decayed during the course of ages having been swept away; wall-like sides to the valleys; the truncation of hill spurs so that they end with triangular facets, and the occurrence of the side valleys high upon the flanks of the main valley. All these features are well developed beside the fiords of Dalmatia, and the exhibition of a series of photographs of glaciated localities in Scotland and Switzerland and

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of the Dalmatian coast showed the many striking resemblances in form. These features, however, in Dalmatia have been produced by non-glacial agencies. There are some small glacial deposits on the highest mountains of Montenegro and Herzegovina, but there is no direct evidence of glacier action on the lower country beside the coast.

Professor GREGORY also read a paper on "The Corries of the Campsie Fells." [See *Transactions*, p. 84.]

A discussion took place on several points advanced by Professor Gregory in his paper, in which Dr. Horne, Dr. Falconer, and Mr. Macnair took part.

G. W. TYRRELL.

EXCURSIONS FOR SEASON 1913.

To Glencroe, Arrochar, on Monday, 24th March (Spring Holiday)—Mr. James L. Begg, conductor. An opportunity was given of examining the recent landslip at Glencroe by which the moraine material on the side of the Cobbler has been carried down and spread over the roadway at Craigdhu. The glacial phenomena and solid geology of the Glen were also examined.

To Kelvingrove Museum, on Saturday, 12th April—Mr. Peter Macnair, F.R.S.E., F.G.S., conductor. The party examined the recent additions to the geological collections, including the corals from the Braidwood collection.

To Kilwinning and Saltcoats, on Saturday, 19th April—Mr. G. V. Wilson, B.Sc. (H. M. Geological Survey), conductor. The objects of interest in this excursion were as undernoted:—(1) Millstone Grit lavas and sediments; (2) a small patch of Coal Measures near Smithstone; (3) sections of Upper Limestone and Millstone Grit rocks at Diddup and Glen Burn.

To Hindog Glen, Dalry, on Saturday, 26th April—Mr. John Smith, conductor. The party examined the following objects of interest in a descending order:—(1) White Limestone of Beith; (2) Hurlet Limestone; (3) Hurlet Coal; (4) Four ash beds and agglomerates, the latter containing one band of ash with burnt remains of coniferous wood; (5) lava flows.

To Jock's Burn, Carluke, on Saturday, 3rd May—Mr. Harry R. J. Conacher, conductor. The burn section shows the Lingula Limestone and the first and second Kingshaw seams, with exceedingly fossiliferous shales, which also contain fine stellate crystals of gypsum. In bings from old ironstone workings there are many fragments of "white trap" containing plastic hydrocarbons which have been derived from the shales into which the trap has been intruded.

To Bathgate, on Saturday, 10th May—Dr. J. D. Falconer, M.A., F.G.S., F.R.S.E., conductor. An opportunity was given in this excursion to observe the physical geography of the Bathgate district; the Hurlet Limestone with its associated igneous and sedimentary rocks, and characteristic fossils; the Bathgate volcanic series with

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siliceo-calcareous intercalations, and intrusions of quartz-dolerite; petrographical characters, and effects of faulting were also examined.

To Seedhill Clayfield, Paisley, on Wednesday, 14th May (evening excursion)—Mr. Duncan Smith, conductor. The object of this excursion was to examine the Post-Tertiary deposits occurring in the clayfield. These consist of surface soil, earthy clay, yellow stony clay, black clay with an abundance of shells, &c., and a laminated sandy clay. The total depth of cutting is about 28 feet, and as the surface datum is about 30 feet above sea-level, the lowest part of the section is thus about co-incident with sea-level. Stones of various kinds—granite, grit, sandstone, porphyritic basalt—are in greater or less abundance.

To the Corries of Balglass, on Tuesday, 20th May (King's Birthday)—Prof. J. W. Gregory, D.Sc., F.R.S., F.G.S., conductor. The object of this excursion was to examine the corries of the Campsie range. The walking distance, returning by way of Killearn, is about 13 miles, but the party sub-divided, one part returning direct over the hills and the other by means of the Fintry Road, in order to see the one local rock which contains clear fresh nepheline.

To Inchinnan, on Wednesday, 28th May (evening excursion)—Mr. James Steel, conductor. The following were the objects of interest in this excursion:—(1) Chariot of Saint Conval; (2) the old bridge of Inchinnan; (3) Celtic and Templar stones in Inchinnan churchyard; (4) ancient barracks and canal; (5) battlefield, twelfth century; (6) boulders on the Bloody Mire.

To Baldernock Linn, Milngavie, on Wednesday, 4th June (evening excursion)—Mr. Harry R. J. Conacher, conductor. The party saw the Baldernock Limestone—a white, entomostracan deposit underlying the Hurlet Limestone. The Glen Wynd Limestone is also visible, with the line of erosion which accompanies it. The Hurlet Coal is broken up by a dolerite intrusion which has thoroughly coked it. At Dowans, on the way to the Linn, the Craigen Glen beds were seen, also involved in an intrusion. These beds are the equivalent of the Hollybush Limestone.

To Upper Greenock, Loch Thom, and Skelmorlie, on Saturday, 7th June—Mr. J. W. Reoch, conductor. Leaving Upper Greenock, the party passed from the Calciferous Sandstone Series on to the overlying lavas, and followed the aqueduct of Shaw's Waterworks to Shielhill Glen, and onwards to the reservoir. In favourable weather a commanding and extensive view of the Clyde estuary and the southern Highlands is opened up *en route*, and geological features on a large scale modifying the scenery are to be noted. South of Dunrod Hill the Calciferous Sandstones again emerge from beneath the lavas, and on the Rotten Burn, near Loch Thom, there is a good section of the Cementstones. The party thence passed down to the Upper Old Red Sandstones, following over these by the aqueduct to Kelly Dam, and down the Kelly Burn to Skelmorlie.

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To Robroyston Brickworks, on Wednesday, 11th June (evening excursion)—Mr. Robert W. Dron, A.M.Inst.C.E., conductor. The object of this excursion was to examine the extensive evidence of disturbance caused by a 40-fathom downthrow fault which is to be seen in crushed coal seams and limestone bands, &c.

To Gryffe Water, on Saturday, 21st June—Mr. Peter Macnair, F.R.S.E., F.G.S., conductor. A remarkably clear section of the Lower Limestone series was examined in the Gryffe Water between the Bridge of Weir and the village of Crosslea. The section is about a mile and a half in length, the limestones being faulted against the volcanics. The Hollybush Limestone and Sandstone are exposed near the base of the section; these pass upwards into the Blackbyre Limestone and the different members of the Hurlet series, including the Hurlet Limestone, which are succeeded further down stream by the Blackhall Limestone and its associated strata. At Crosslea the Hosie Limestone in two bands marks the upper limit of the Lower Limestone Series.

To Eaglesham, on Saturday, 6th September—Mr. George C. Watson, conductor. The object of this excursion was to examine the high level terraces at Enoch (described by Prof. James Geikie in his "Great Ice Age," chapter xiv.). The party also had an opportunity of seeing a section of sediments overlying and almost entirely derived from the Clyde Volcanic Plateau. This section suggests seashore deposits with large and small boulders dropped from floating ice, and is of Calciferous Sandstone age.

To Lugton and Uplawmoor, on Saturday, 20th September (joint excursion with Glasgow University Geological Society)—Mr. D. Ferguson, M.Inst.M.E., F.R.G.S., conductor. The party first visited the sandstone exposures in the Shilford Quarries on the Caledonian Railway line to Ardrossan, where was also seen an outcrop of the basal limestone rich in organisms; thence travelling westward about half a mile, Uplawmoor Station was reached, where the limestone was seen outcropping on the ash beds of lavas of Calciferous Sandstone age. Fossils may be obtained in the junction line of the limestone and the ash beds. Lugton Quarries were next examined, and *en route* an opportunity was taken to demonstrate the stratigraphical relationship of the Carboniferous Limestone sequence in Ayrshire. In the Lugton Quarries the basal limestone is well developed, and fossils are frequently obtained.

To Great Cumbrae, on Monday, 29th September (Autumn Holiday)—Mr. G. W. Tyrrell, A.R.C.Sc., F.G.S., conductor. The party visited exposures of raised beach material near Portachur Point, then proceeding by the west coast some igneous rocks were seen, including trachytes at Craig nan Fitheach, Craiglockhart basalt at Bell Craig, containing large augite and olivine phenocrysts, and andesitic pitchstone at Eerie Port. Crossing over to the east side of the island they visited east-and-west dykes, trachyte dykes, the "Lion Rock," and exposures of Old Red Sandstone.

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ABSTRACT OF THE TREASURER'S ACCOUNTS FOR THE YEAR ENDED 30TH SEPTEMBER, 1912.

CASH ACCOUNT.

RECEIPTS.

To Cash in Bank on Deposit, ...	£54 0 0		
,, Do. in Treasurer's hands, ...	3 1 10		
,, Do. Mr. C. R. Cowie's Donation, ...	1 12 11		
		£58 14 9	
,, Subscriptions for current year (including 14 new Ordinary Members)—141 at 10/, ...		70 10 0	
,, Do. 2 at 7/6, ...		0 15 0	
,, Do. Arrears—6 at 10/, ...		3 0 0	
,, Associate Members' Subscriptions—9 at 2/6, ...		1 2 6	
,, Mitchell Library for copies of *Transactions*, ...		1 15 10	
,, *Transactions* Sold, per Hon. Librarian, ...		4 5 8	
,, Jubilee Volume Sold, ...		0 4 6	
,, Interest on Funds, ...		5 12 1	
,, Do. Mr. C. R. Cowie's Donation, ...		3 5 11	
		£149 6 3	

EXPENDITURE.

By *Transactions*—			
Printing and Publishing Vol. XIV., Part 2, and for Reprints of Papers, ...	£52 19 6		
Postages and Outlays *re* do., ...	3 1 2		
		£56 0 8	
,, Library—New Books and Bookbinding Maps and Magazines,		7 5 0	
,, Printing and Postage of Circulars and Excursion Booklets, and Advertising, ...		19 19 11	
,, Rent, Insurance, and Attendance, ...		10 10 0	
,, Disbursements by Hon. Secretaries, Postages, Stationery, and Petty Expenses, ...		2 10 6	
,, Collector's Commission, ...		2 9 0	
,, Lantern Expenses, ...		3 1 3	
,, Subscription to Marine Biological Association, 1912, ..		1 1 0	
,, ,, to Palæontographical Association, 1912, ..		1 1 0	
,, Delegates' Expenses to the British Association, Dundee, 1912,		1 10 0	
,, Mr. C. R. Cowie's Donation—			
Interest to Martinmas, 1911, paid to Glasgow University, ...	£1 13 0		
Do., to Royal Technical College, Glasgow,	1 12 11		
		3 5 11	
,, Cash in Bank on Deposit, ...	£36 0 0		
,, Do. in Treasurer's Hands, ...	2 19 1		
,, Do. Mr. C. R. Cowie's Donation, ...	1 12 11		
		40 12 0	
		£149 6 3	

LIFE SUBSCRIPTION ACCOUNT.

Sept. 30, 1912.—To Balance to Credit, ...	£177 5 0	September 30, 1911.—By Balance from last Account, ...	£177 5 0
	£177 5 0		£177 5 0

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ABSTRACT OF THE TREASURER'S ACCOUNTS FOR THE YEAR ENDED 30TH SEPTEMBER, 1912.

Mr. CHARLES R. COWIE'S DONATION.

Sept. 30, 1912.—To Glasgow University, one-half of Interest to Martinmas, 1911,		£1	13	0	
,, The Royal Technical College, Glasgow, one half of Interest to do.,		1	12	11	
Balance to Credit,		101	12	11	
	£104	18	10		
Sept. 30, 1911.—By Balance from last Account,				£101	12 11
Sept. 30, 1912.— ,, One year's interest to Whitsunday, 1912,				3	5 11
				£104	18 10

STOCK ACCOUNT.

To Life Subscription Account,		£177	5	0	
,, Mr. Charles R. Cowie's Donation and accrued Interest,		101	12	11	
,, Capital Account,*		531	14	1	
* NOTE.—Subject to cost of publishing *Transactions*.					
	£810	12	0		
By Invested with Campbeltown Corporation under Mortgage at 3½ per cent.,	£170	0	0		
,, Cash in Bank and in Hand,	38	19	1		
				£208	19 1
,, Property—Books in the Library,	£440	0	0		
Furniture, Bookcases, & Microscope,	60	0	0		
				500	0 0
,, Mr. Charles R. Cowie's Donation—Invested with Campbeltown Corporation under Mortgage at 3½ per cent.,	£100	0	0		
,, Do., Interest accrued to Whitsunday, 1912,	1	12	11		
				101	12 11
				£810	12 0

GLASGOW, *6th November*, 1912.—Examined, compared with relative Vouchers and Securities, and found correct, the balance in Treasurer's hands being Four Pounds Twelve Shillings; Two Pounds Nineteen Shillings and One Penny being due to Society, and One Pound Twelve Shillings and Elevenpence being Interest accrued on Mr. Charles R. Cowie's Donation.

D. PEARSON,
ARCH. MACINTYRE, } *Auditors.*

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THE GEOLOGICAL SOCIETY OF GLASGOW.

Office-Bearers for Session 1912-1913.

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Dr. John Horne, F.R.S., F.G.S.

Vice-Presidents—

For Three Years.

Mr. G. W. Tyrrell, A.R.C.Sc., F.G.S.

For Two Years.	*For One Year.*
Prof. J. W. Gregory, D.Sc., F.R.S., F.G.S.	Mr. Archibald A. Young.

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Mr. R. W. Dron.	Mr. Duncan Smith.	Mr. James L. Begg.
Dr. J. D. Falconer.	Mr. P. A. Leitch.	Mr. James Steel.
Mr. Wm. R. Smellie.	Mr. Andrew C. Kerr.	Mr. A. B. Motherwell.

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Mr. James W. Reoch, 22 Montgomerie Street, Kelvinside.

Honorary Treasurer—

Mr. E. Hall Wight, 150 Hope Street.

Honorary Librarian—

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Auditors—

Mr. David Pearson. | Mr. A. Macintyre.

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The Honorary Secretaries are "ex-officio" Members of all the above Committees.

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TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY OF GLASGOW.

No. X.—The Tertiary Composite Sill of South Bute. By W. R. Smellie, M.A., B.Sc., Baxter Demonstrator in Geology, Glasgow University.

[Read 11th December, 1913.]

The Tertiary composite sill of South Bute has already been described,[1] but as the evidence brought to light by the present work will entail fundamental alterations, not only in the description but in the conclusions to be drawn therefrom, it will be advisable to give a short *résumé* of previous work. The sill has been described as consisting of three sheets, a thick inner sheet of dolerite flanked by two marginal sheets of quartz-porphyry. In two places a fourth sheet is observed, a thin basic sheet interposing between the lower acid sheet and the country rock. The acid sheets make very irregular junctions with the dolerite core, and contain xenoliths torn from it, while the dolerite contains xenocrysts of quartz and felspar obviously similar to the crystals in the acid rock. The conclusion arrived at was that an earlier acid sill had been eviscerated by a doleritic magma working along the centre, thus accounting for the marginal position of the acid sheets, the xenocrysts in the dolerite, and the irregular junctions. This theory has three weak points—(1) It fails to explain the xenoliths in the acid rock, (2) it ignores the two occurrences of a fourth sheet, (3) it forms a complete exception to the order of events found to

[1] *The Geology of North Arran, South Bute, &c.* (Mem. Geol. Surv., Scotland), 1903.

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persist in the composite sills of Skye of the same age. This reversal of the usual order of intrusion has rendered this sill quite remarkable, and has thus called for two references from Harker [2&3]. Though thus quoted as an exception, a footnote[2] very shrewdly casts doubt on its claim to be considered as such. In the present paper it will be shown that the sill is a symmetrical one of five sheets arranged B A B A B, instead of one of three sheets arranged A B A, and that the acid rock has been intruded later. Though thus robbed of its spurious interest as a notable exception, the composite sill of South Bute still presents many points of legitimate interest, and has proved a fruitful working ground.

Field Relations.—The accompanying map shows the outcrop of the sill and its relations to the other rocks in the district. It is intruded into the Calciferous Sandstone lavas. Rising from the sea in a perpendicular cliff, it forms the promontory of Roinn Clùmhach, and, running N.W. towards Torr Mor, it forms an escarpment which cuts the lava scarps at a very low angle. In this part of its course it will be noticed that the outcrop is discontinuous at one point, and a tongue projects into the lower lavas. After attaining a height of over 400 feet just south of Torr Mor, it turns abruptly at right angles to its former course, and thus cuts directly across the strike of the lavas, forming a well-marked topographical feature. The tall, rudely columnar escarpment, capped by the white quartz-porphyry, truncates the low-lying lava ridges, and is a striking instance of structure dominating form. After pursuing a curved course of nearly a mile, and capping St. Blane's Hill, the sill turns towards the sea; Bar Hill is entirely formed by the sill, which here assumes laccolitic form before plunging again into the sea, this time at Uamh Capuill, where a steep cliff is again formed. Throughout its course, as a glance at the map will show, the sill shows a marked tendency to alternate thickening and thinning. Much of this is due to the crossing of obstructions; for example, just south of Torr Mor the outcrop is very

[2] *The Tertiary Igneous Rocks of Skye* (Mem. Geol. Surv. Scotland), 1904, p. 199.

[3] *The Natural History of Igneous Rocks*, p. 344.

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Map of South Bute to show Composite Sill.

[Escarpments running N.W. to S.E. are formed by Calciferous Sandstone Lavas. Outcrop of Permo-Carboniferous Sill to the south of the Composite Sill is copied roughly from the 1-inch Geol. Surv. Sheet.]

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narrow where the composite sill crosses the Permo-Carboniferous olivine-dolerite sill, but widens considerably after negotiating the hindrance.

The age of the composite sill can be demonstrated with a facility and certainty not usually met with outside of text-books. The following facts and a glance at the map will make this clear:—

(1) The composite sill is intruded into and cuts across the Calciferous Sandstone lavas. Therefore it is later than they.

(2) The composite sill cuts the olivine-dolerite sill. Now, the olivine-dolerite sill is later than the Calciferous Sandstone traps, which it cuts, and from this and its petrological affinities its age can be settled as Permo-Carboniferous. Therefore the composite sill is later than the Permian vulcanicity.

(3) None of the faults in the area displace the composite sill, though the olivine-dolerite sill is displaced.

(4) Near Uamh Capuill the composite sill is cut by a N.E. to S.W. Tertiary dyke, and therefore the sill is earlier than the dyke. Thus the following conclusions can be drawn:—The composite sill is later than Permian, and later than faults which displace Permian rocks. The Mesozoic was a period of igneous inactivity, and not till Tertiary times do igneous rocks occur again. A Tertiary dyke cuts the sill. Now, in the phase of minor intrusives, which marked the close of Tertiary vulcanicity, the injection of basic dykes was the last act, and followed the intrusion of the composite sills. In this way the Tertiary age of the Bute composite sill is arrived at, even supposing its petrological affinities with Skye and Arran were not available as a guide.

Faults.—The area in which the sill occurs is broken by faults which run from N.W. to S.E. and downthrow to the N.E. The fault forming Glen Callum is the only one in this part shown on the Geological Survey Map (Sheet 21), but there is certainly another running past South Garrochty to the sea at Port Uisg, where the sandstone under the lavas is exposed on the shore. It is very probable that still another fault runs along the foot of St. Blane's Hill and out to the sea at Loch na Leighe, for here the composite sill, though not displaced, shows much

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shattering as if by slight movements along the old fault plane. On the Survey Map faults are mapped to the N.W., and these, if produced to the S.E., would coincide with the faults described above. The age of the faulting is probably early Tertiary, as the faults break the Permo-Carboniferous sill, but not the composite sill, which is late Tertiary.

The Order of Intrusion.

The order of intrusion can be quite conclusively settled from the field evidence. Normally, the sill is composed of five sheets (see diagram), which are arranged in the following order:—Working upwards from the lavas the first sheet met with is an 18-inch sheet of fine-grained blue dolerite charged with xenocrysts of quartz and felspar. The junction between this and the overlying sheet of quartz-porphyry is both sharp and even. The quartz-porphyry is very uniform in appearance throughout, being a whitish rock composed of numerous quartz and felspar crystals set in a fine drusy groundmass. This sheet is usually from 2 to 4 feet thick, but at Loch na Leighe it has thickened out to about 10 feet. It contains numerous xenoliths of the dolerite, which vary greatly in size, but always show sharp, well-defined outlines, and always contain xenocrysts. The upper margin of this acid sheet is very irregular, and tongues reach a long way into the overlying dolerite, which is the central sheet of the sill and usually very thick, ranging up to 50 or 60 feet. This thick core of dolerite shows rude columnar and spheroidal jointing, and along these joints the quartz-porphyry has worked in a most remarkable manner. The central dolerite is like the marginal sheet and the xenoliths, and like them is charged with xenocrysts. Working upwards, the xenocrysts fall off in number, and the grain of the dolerite becomes coarser, till in the centre of the thick mass no xenocrysts are got. Continuing upwards, the xenocrysts reappear gradually, and the grain of the dolerite becomes finer, till the upper sheet of quartz-porphyry is met with. The junction here is similar to the junction with the lower quartz-porphyry sheet, that is, very irregular. This upper acid sheet is similar in all respects to the lower, contains xenoliths, and

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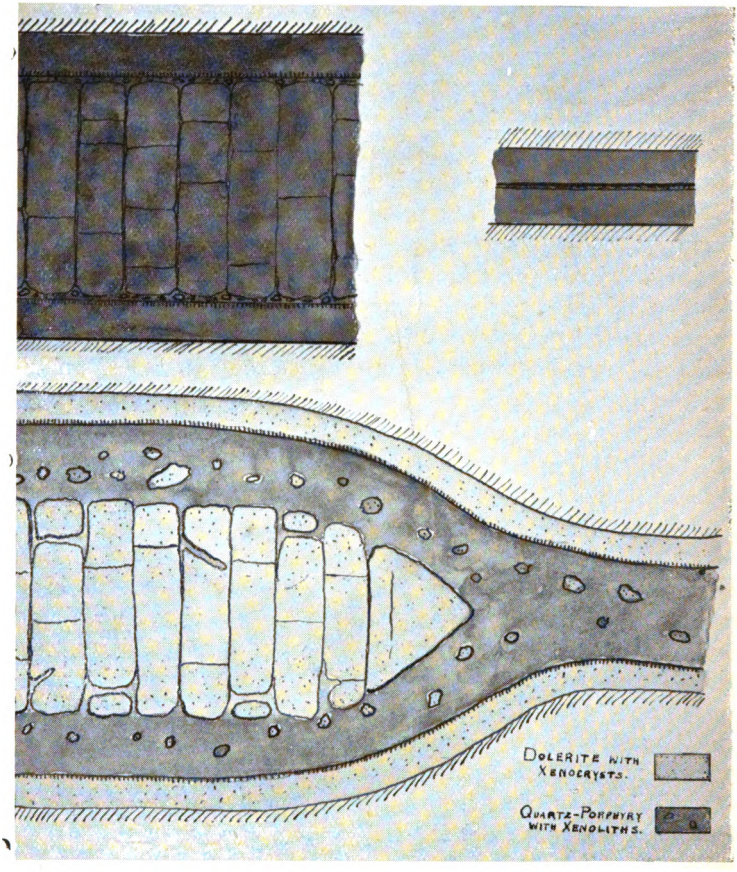
Plan of Thick Dyke.
16 Feet.

Plan of Thin Dyke.
4 Feet.



Diagrammatic Section of Composite Sill.

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forms a sharp and regular junction with the 18-inch marginal sheet of dolerite. The two thin marginal sheets of dolerite are most uniform and constant, and are always present even when the thick dolerite core has disappeared. They show one chilled margin each, namely, the outside margin against the lavas. Such being the description of the sill, it does seem difficult at first sight to say which rock came first. Considering the dolerite alone, the contained xenocrysts obviously similar to the crystals in the acid rock would support the view that the dolerite was intruded last, and picked up the quartz and felspar from the acid rock. If, in addition, the thin marginal dolerite sheets have been unnoticed, the case seems complete for the evisceration of a quartz-porphyry sill by a subsequent dolerite magma, especially as the junctions made by the dolerite core with the acid sheets are so complicated that in places it seems difficult to tell which rock is enclosing the other. However, the presence of the dolerite xenoliths in the acid rock, and the marginal sheets of dolerite render this theory untenable. The following seems to be the only history of the case that accords with the evidence, and, as will be seen later, microscopic evidence confirms it:—Suppose the dolerite magma, while still in the magma reservoir or in the channel of uprise, be impregnated with the acid magma and then intruded into the Calciferous Sandstone lavas, it would arrive in its present position acidified and charged with quartz and felspar crystals, and it would crystallise and become solid. The form this mass of dolerite would be likely to assume is got by observing some of the basic dykes in the district (see diagram). When the dyke is thick it frequently happens that fine-grained unjointed margins about a foot thick adhere firmly to the country rock, while the massive centre of the dyke assumes columnar joints, and is separated from the margins by planes of weakness containing much shattered rock belonging to neither the columnar centre nor the margins. On the other hand, a thin dyke of, say, 3 or 4 feet would give the adhering margins but only one plane of weakness, there being no central columnar mass. Now, suppose the dolerite of the sill to be intruded and solidified (though not necessarily cool), and to have assumed this form.

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The acid rock is now intruded, and naturally enters along the lines of least resistance, namely, the planes of weakness dividing the margins from the columnar interior. Coming along those lines, the acid rock would be expected to accomplish three things—(1) It would pick up all loose rock along the planes of weakness and carry on undigested fragments as xenoliths; (2) being at a high temperature and (for an acid magma) very mobile, it would work its way up columnar joints, encompass xenoliths by working round spheroidal joints, and thus form a very irregular junction with the columnar core of dolerite; (3) with the uniformly thick, unjointed margins it would form an even junction. In fact, throughout all the exposures of the sill there is only one point at which the quartz-porphyry is found to penetrate the lower basic sheet and reach the lavas below. The volume of the quartz-porphyry being comparatively small, it is unable to assimilate much of the dolerite to produce anything in the way of an intermediate or transition rock, and so junctions, though often irregular, are always sharp. Thus, going on the assumption that the dolerite would assume the form which intrusions of similar rock as dykes often take up, the positions and peculiarities of the various sheets of the composite sill are very simply explained, and, as will be seen below, variations in the sill are of such a nature that they add additional evidence in support of this hypothesis.

Variations in the Sill.—Throughout most of the area the sill is remarkably uniform, the five sheets are present, their thickness fairly constant (excepting the dolerite core), and specimens from the different localities indistinguishable from each other. However, in two places this uniformity is relieved by exceptions. Tracing the sill from the shore, at a point about a quarter of a mile from Roinn Clùmhach the dolerite core is found to thin out and eventually disappear, so that the two acid sheets coalesce, and the sill becomes one of three sheets arranged B A B. This arrangement is best seen in the tongue which projects from the main mass of the sill. The thickness of the dolerite here is comparable with that of the thin dyke (see diagram), hence the one plane of weakness and the reduction to three sheets. In this projecting tongue also, as the dolerite thickens, the inner

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core can be seen gradually dividing the combined acid sheets, and thus giving once more the five sheets (see diagram). Near this same point (see map) there is a gap in the outcrop; the sill has failed to penetrate the lavas far enough to be exposed. The last rock seen at the gap is the acid rock, as if it had pushed out further even than the thin marginal sheets of dolerite, although this cannot be definitely ascertained. However, the most interesting feature of this part is that the acid rock has here solidified as a most perfect pitchstone porphyry, a black obsidian-like glass set with numerous quartz and felspar crystals. The rock thus formed is of most handsome appearance, and must rank as one of the most beautiful rocks in the West of Scotland. Since this is the only part of the sill where the acid rock assumes this facies, it is natural, in seeking an explanation, to consider in what respects this part of the sill differs from the rest so as to produce conditions of cooling suitable for the formation of such a perfect glass. In this connection it is found that there are two main points that would bring about conditions experienced by no other part of the sill—(1) The dolerite core has disappeared; in other words, the volume of the dolerite at this part has only been sufficient to form the two thin marginal sheets, and at one point (where the most perfect glass occurs) it is probable that the dolerite petered out altogether; (2) the sill here is close up to the Glen Callum fault plane, which probably marked the original eastern extension of the sill. These are sufficient to account for the rapid cooling necessary to produce the pitchstone facies. For, as we cannot suppose any considerable interval of time to elapse between the intrusions of the basic and acid magmas, it is reasonable to assume that the acid magma was intruded when the dolerite was solid certainly, but still at a high temperature, for the cooling curve of a large mass of dolerite such as this would decay very gradually to the temperature of its surroundings. Thus throughout the sill generally the acid magma would cool slowly against the great mass of slowly cooling dolerite, and hence the holocrystalline groundmass of the quartz-porphyry; but where the pitchstone-porphyry occurs the volume of dolerite is negligible, and the position is at the original limit of the sill, so that here

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the acid magma, intruded into cold rock, would suffer rapid cooling, since its own volume is not great, and hence it would solidify with a glassy groundmass.

The second variation in the sill occurs close by where it re-enters the sea at Uamh Capuill. Beside the cave here the lower part of the sill has enclosed a large lenticle of a rock, which will be referred to provisionally as bostonite, as the thin section matches perfectly the figure and description of bostonite given by Harker.[4] Further confirmation of the order of intrusion is got here, for basic margins adhere not only against the lavas on the outside, but also to the lenticle of bostonite, so that, although the lenticle partially splits the lower sheet of quartz-porphyry, they are never in contact, the margin of dolerite always intervening. A section through the sill at this point would show eight sheets arranged from top to bottom B A B A B (bostonite) B A B.

Petrology.

In many respects the phenomena evidenced by the thin sections of the rocks of this sill are similar to those described and figured as occurring in the Tertiary composite sills of Skye.[5] However, the Bute composite sill does not exactly conform to the Skye type, but differs in several essentials. In the Skye sills the acid rock is an overwhelming proportion to the basic rock, and the large volume of acid magma is able to work great changes when intruded into the comparatively insignificant basic sheets; so much so that in some cases pre-existing basic sheets have been so successfully attacked that they are now reduced to a line of xenoliths in the acid rock. The preponderance of the acid rock is so constant and in every case the same rude proportion is so well maintained that Mr. Harker tentatively puts this forward as evidence of these rocks being, in Broggers' phrase, complementary products of differentiation. In the Bute sill the reverse is the case, for,

[4] *Petrology for Students*, 4th ed. (1908), p. 130.

[5] Harker in *The Tertiary Igneous Rocks of Skye* (Mem. Geol. Surv., Scotland), 1904.

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where 10 feet would be an over-estimate for the average thickness of the joint acid sheets, the combined basic sheets will easily average 40 feet. Such being the case, it is clear that the acid rock will effect little in the way of acidification of the basic rock after intrusion, and the dolerite being hard and solid when attacked would further hinder any subsequent silicification. Thus practically all the acidification that the dolerite has suffered (and it is considerable) must be attributed to impregnation by the acid magma immediately before intrusion. In Skye the reverse holds good, for, although in some cases the acidification is partly anterior to intrusion, the bulk of it is considered to have been effected by the acid rock after intrusion. The dolerite has not only been silicified at this time by molecular transference, but whole crystals from the acid rock have passed over, and are found well within the basic rock. In Bute there is nothing to indicate a similar phenomenon; on the contrary, the special conditions are such as to render a subsequent transference of crystals highly improbable.

The Dolerite.—In the cliff section at Roinn Clùmhach, where the dolerite is between 30 and 40 feet thick, a series of specimens was taken, two being taken from each marginal sheet and one from every 5 feet of the thick central mass. Each specimen had its specific gravity taken, and a thin section cut. The slides cut from the outside borders of the marginal sheets are very fine in the grain, and contain much dark basic glass, in which are set numerous small bifid labradorite laths, irregular grains of rhombic and monoclinic pyroxene, small cubes of magnetite, and occasional blebs of quartz. Xenocrysts of quartz and oligoclase are numerous. The position of this glassy type shows that the three dolerite sheets were originally one the selvages of which were chilled against the lavas. Working inwards, the dolerite becomes holocrystalline in the space of a few inches, and from this point to the centre of the sill a gradual coarsening of the grain of the rock can be observed, although in this section coarse dolerite is not got, and so one description will serve for the series. The rock is composed of laths of acid labradorite, much granular pyroxene, augite, and a faintly pleochroic rhombic variety in equal proportions, numerous

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small biotites intensely pleochroic, well-formed magnetites, a few apatite needles, and occasionally interstitial quartz. Though one description will serve for the rock, the xenocrysts will require separate treatment. One slide showed rather plentiful interstitial quartz, and, in addition, two or three phenocrysts of labradorite, fissured but very fresh. This same specimen showed abnormally low specific gravity 2·69. Throughout this series the structure was granulitic in Professor Judd's sense,[6] and never ophitic. Good ophitic structure is got in the coarse rock taken from the scarp between Torr Mor and Loch na Leighe, where the sill is very thick, but this rock has been already well described.[7] The study of the xenocrysts in the thin sections made from different parts of the dolerite yields striking evidence bearing on the history of the consolidation of the magma. The xenocrysts are of quartz in small blebs seldom more than $\frac{1}{8}$ inch in diameter, and of felspar, a glassy oligoclase, some individuals of which attain a size of $\frac{1}{2}$ inch, although the majority are much smaller. Working from the glassy margins of the dolerite in towards the middle of the central sheet, the following points can be observed:—

(1) The xenocrysts are numerous in the glassy margin, and show clean outlines, the felspar being as perfectly shaped as it is in the parent quartz-porphyry.

(2) A foot or so in, the quartz shows a thin reaction rim of pyroxene, but the felspar remains as before.

(3) Further in still the pyroxene envelope increases in thickness till only a small quartz nucleus in a nodule of radiating pyroxene prisms remains (Plate, Fig. 4). The next stage is a nodule of pyroxene with no trace of the original quartz. In these augite predominates over the rhombic pyroxene. Finally, in the heart of the sill these nodules disappear, being either dissipated or, more probably, never formed as such. The behaviour of the felspar is very different. No reaction rim forms, and for a time no change takes place. Following the felspars in further, they are seen

[6] *Tertiary Gabbros, &c., in Scotland and Ireland,* Q.J.G.S. (1886), vol. xlii., p. 68.

[7] Harker in *The Geology of North Arran, South Bute, &c.* (Mem. Geol. Surv., Scotland), 1903.

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to become worn, dusty, and dilapidated, masses of the groundmass of the dolerite are thrust into them, great bays and inlets are eaten out of them, and, finally, by the time coarse dolerite is reached they have disappeared. These facts are to be interpreted in the following way:—The dolerite magma must have been impregnated by the acid magma bearing quartz and felspar crystals *immediately* before intrusion, so that the rapidly cooled selvages sealed up the xenocrysts before they had undergone any change. The interior of the sill would remain liquid and at high temperature for some time, the time decreasing as the margins are approached. This liquid basic magma, unsaturated with silica, would readily react with the quartz grains, thus giving the pyroxene envelopes; and the gradual increase in the thickness of these reaction rims as the distance from the margins increases indicates that the magma solidified from the margins inwards, so that the further in the situation of the quartz grain the longer could the molten magma react with it. The behaviour of the oligoclase xenocrysts is different, for the silica in them being already combined with bases, they are chemically insoluble in the dolerite magma, so for some time they remain unaffected. But near the centre of the thick dolerite core, which must have remained liquid and at high temperature for a considerable time, they disappear after having showed signs of softening and mechanical abuse but no chemical change, so it is probable that this part of the magma remained sufficiently long at a temperature near the melting point of oligoclase to incorporate them by physical solution. In this connection it is noteworthy that the felspar in the coarse dolerite is no longer labradorite but andesine, giving 15 degrees extinction in sections perpendicular to (010), so that the oligoclase substance must have gone to help to produce andesine from the labradorite. The specific gravity of the series of specimens through the dolerite at Roinn Clùmhach is fairly constant. The average is 2·74 and the range 2·72 to 2·76, the variation being quite irregular. This excepts the specimen already mentioned, which gave S.G. 2·69, and contained labradorite phenocrysts. Had these labradorites been general it would have been impossible

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to account for the disappearance of the felspar xenocrysts by the foregoing explanation.

Acidification.

It will be seen that all the foregoing evidence indicates a very considerable acidification of the dolerite *previous* to intrusion. The fact that xenocrysts are numerous near the quartz-porphyry is due to the quartz-porphyry having been intruded near the edges of the dolerite where the xenocrysts had not been dissolved, and there is no causal connection between the number of xenocrysts and the position of the quartz-porphyry sheets. This is further borne out by the unvarying specific gravity, which shows that while on the margins the xenocrysts are present in the flesh, so to speak, in the centre they are present in the spirit. But for the acidification the dolerite would probably have crystallised as a basic olivine-dolerite. Instead, rhombic pyroxene (frequently an indicator of silicification) occurs all the way through, the mineral biotite is plentiful, and would indicate an addition of potash, while the felspar is acid labradorite and andesine. Occasionally interstitial quartz is seen and quartz is also got in microscopic druses, where it is usually associated with calcite. An attempt has been made to estimate the percentage of the acid magma which has been added to the basic magma to produce the present dolerite. The method is exceedingly simple, and seems perfectly sound, but, as will be seen, the results work out so surprisingly in accordance with what they ought to be that one is inclined to suspect some underlying fallacy. The method depends on the unaltered character of the xenocrysts on the margins of the dolerite, and on the justifiable assumption that in the acid magma the phenocrysts of quartz and felspar bore the same relation to molten magma that they now bear to groundmass in the quartz-porphyry. Thus the rapidly cooled margins of the dolerite show the xenocrysts unaltered, and the number of these should give a measure of the acid material added to the basic magma. The number of crystals of quartz and felspar showing on a square inch of surface was counted

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both for quartz-porphyry and marginal dolerite, and averages taken from about two dozen counts gave the following figures:—

Rock.	Quartz.	Felspar.	Total.
Quartz-porphyry, - -	12	12	24
Dolerite (from margin), -	3·2	3·3	6·5

It should be noticed that the proportion of quartz to felspar is practically the same in both rocks, and that is as it should be. Then since the quartz-porphyry contains 24 phenocrysts to the square inch, it can be postulated that 24 to the square inch represents 100 per cent. acid rock or acid magma, so 6·5 to the square inch would represent 27 per cent. acid magma. Thus the present dolerite is a rock formed by the mixture of 27 per cent. of the acid magma to 73 per cent. of the original basic magma. To test this result the specific gravities of the dolerite and quartz-porphyry were compared with the specific gravity of *unacidified* Tertiary dolerites which are olivine-dolerites, and probably formed from a magma very similar to the original basic magma involved in the Bute case. The average specific gravity of ten specimens from the Great Group of Dolerite Sills[8] is found and compared thus:—

A. Average specific gravity of Skye Tertiary dolerite, - 2·87
B. Average specific gravity of Bute Tertiary Dolerite, - 2·74
C. Average specific gravity of Bute quartz-porphyry, - 2·52

Now, 2·74, the specific gravity of the Bute dolerite, should equal the specific gravity of a rock formed of 73 per cent. of A mixed with 27 per cent. of C.

$$i.e.,\ 2{\cdot}74 \text{ should} = \frac{73 \times 2{\cdot}87 + 27 \times 2{\cdot}52}{100}$$
$$= 2{\cdot}77.$$

In this calculation no allowance has been made for the basification of the quartz-porphyry, but, as will be seen later, that is a negligible factor, and, further, specimens showing any signs of basification were not used in the measurement. The method seems so satisfactory that it is regretted the measurements had to be made from a limited number of hand specimens in the laboratory, but it would be interesting to test it still further

[8] Harker in *The Tertiary Igneous Rocks of Skye* (Mem. Geol. Surv., Scotland), 1904, p. 251.

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by an unlimited number of measurements such as could be made in the field.

Xenoliths.—Apart from the interest attached to the xenoliths of dolerite as indicators of the order and mode of intrusion, they present little of intrinsic importance. They are of various sizes and shapes, but, as might be expected from the position of the dolerite which provided them, they are invariably fine grained. They always show sharp junctions with the enclosing acid rock (see Plate, Figs. 2 and 3), and it would appear that the acid rock has removed and digested the outsides, but has effected little in the way of silicification. Thin sections of the xenoliths are only distinguishable from those of the fine-grained dolerite by the more highly altered state of the ferro-magnesian minerals, and not by any appreciable increase in interstitial quartz or other sign of silicification. Looked at from the other point of view, namely, the effect produced on the acid rock, a local change in the mineral content directly due to the digestion of the dolerite is quite apparent, and this will be dealt with under the description of the acid rock.

The Acid Rock.

Quartz-porphyry.—Throughout the field, with the exception of the small part where the pitchstone-porphyry and other variations occur, the acid rock is very uniform in the hand specimen. The phenocrysts are quartz and felspar. The felspar is a clear glassy variety, but is sometimes badly kaolinised so as to appear white and turbid. Some individuals attain a size of half an inch, and very perfect specimens showing carlsbad twinning can be got from the gravel of the weathered rock. This simple twinning and the glassy appearance have probably been responsible for the felspar having been described in the past as sanidine, but thin sections show, in addition, polysynthetic twinning and an extinction of 5 degrees in sections perpendicular to (010). This would point to the felspar being oligoclase, and this is confirmed by an alkali estimation done by Mr. J. V. Harrison, which showed the felspar to contain no potash, but to be oligoclase of composition $Ab_5\ An_1$. The

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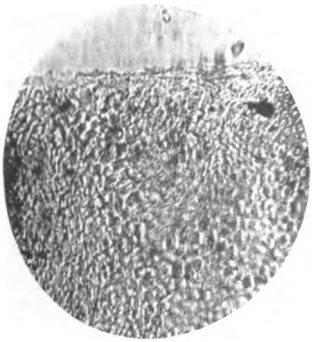

Fig. 1.

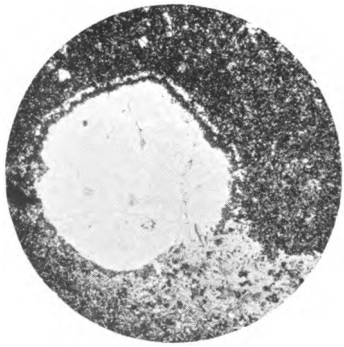

Fig. 2.

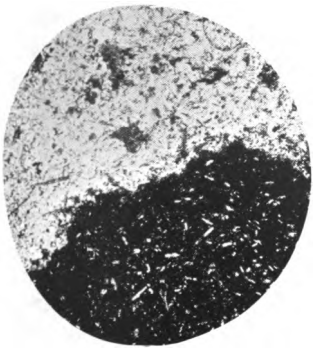

Fig. 3.

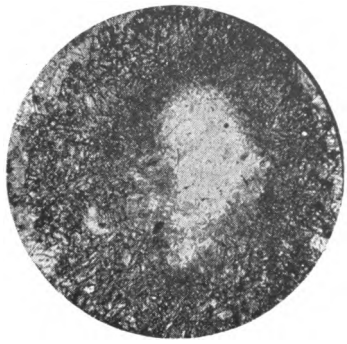

Fig. 4.

Fig. 5.

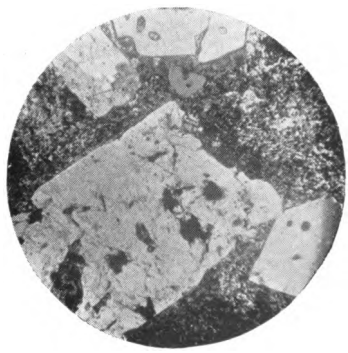

Fig. 6.

Photomicrographs of Portions of Composite Sill.

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quartz appears as small blebs, but under the microscope each bleb is seen to be an optical unity and quite frequently slightly rounded hexagonal sections which are isotropic are observed, so that the quartz should be considered as badly rounded crystals rather than irregular blebs or grains. The felspar is also slightly rounded, and both contain large inclusions of the groundmass. The groundmass is fine, white, and drusy, but the uniformity is shown by the thin section to be only macroscopic, for almost every slice cut is seen under the microscope to present something different in the nature of the groundmass. Generally the normal rock may be described as composed of numerous phenocrysts of quartz and oligoclase set in a groundmass of quartz, felspar and sparse biotite, with well-formed cubes of magnetite and large sporadic pyroxene. Occasionally grains of zircon occur, and in one slide a cluster of small rutile crystals appeared. These are the constituent minerals of the normal *unbasified* rock, and the presence of both biotite and magnetite in crystalline parts of the groundmass included in the phenocrysts proves that these minerals are natural in the acid rock. While the normal mineral content of the rock can be given in this way, generalisations with regard to the structure are difficult, and to account for them is still more so. The groundmass is sometimes a felt of felspar laths in quartz, at other times it is spherulitic, and, again, a fairly coarse granophyric type is got. A specimen was taken from the upper acid sheet above Glen Callum Bay, because it occurred in a regular nest of xenoliths and looked dark in colour, the argument being that its groundmass would show maximum basification. The thin section showed an utter lack of basification, biotite and magnetite were scarce, and practically the whole groundmass was composed of very regular micrographic intergrowths mostly in fine parallel rods, but also in the form figured (Plate, Fig. 1). Another section cut from apparently normal rock from the top of St. Blane's Hill shows small pyroxene microlites like those in the pitchstone, but set in a holocrystalline groundmass, as if this was a devitrified pitchstone. There is no evidence to account for this, for even if the later dyke crossing here is requisitioned to supply the heat for devitrification, a reason has

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still to be found for the original glass. At the small tongue projecting from the sill where the rock must have been rapidly cooled some quartz-porphyry is got, which, while little different in thin section, is quite distinguishable in the hand specimen. One type has a whitish cherty-looking groundmass, while the groundmass of another from close against the dolerite is dark blue like a basalt. Thin sections show these to have a granophyric groundmass, which polarises in sectors, and which is heavily charged with an indeterminate black dust.

The pitchstone-porphyry is the most noteworthy variation of the acid rock, both on account of its appearance as a rock and its omission from previous descriptions of the sill. Professor Judd[9] has described a pitchstone-porphyry which somewhat resembles the Bute rock in the hand specimen, but is lacking in number and size of phenocrysts, and is a glassy facies of a dacite. Another pitchstone-porphyry has been described and figured from Arran[10], and, though quite unlike in the hand specimen, this rock, in common with many of the Arran pitchstones, is very comparable with the Bute rock in mineral content and texture. Though the exposure of the Bute pitchstone-porphyry measures only a few feet and is uniform in appearance, thin sections show variations which may be summed under two main types—(1) This type (Plate, Fig. 5) has the phenocrysts set in a uniformly brown belonitic glass, which contains few or no large microlites. In cutting the thin sections well-marked flow lines could be seen sweeping round the phenocrysts when the section was thick, but these disappeared by the time regulation thinness had been attained. (2) The second type differs in the nature of the groundmass. This time it is colourless and crowded with small green microlites (Plate, Fig. 3). The quartz and oligoclase phenocrysts need no further description, as they only differ from those in the quartz-porphyry in the nature of the inclusions. The inclusions always correspond with the groundmass, and if any difference exists it

[9] *The Volcanic Rocks of the North-East of Fife*, Q.J.G.S. (1886), vol. xlii., p. 427.

[10] Scott in *The Pitchstones of South Arran*, Tr. Geol. Soc. Glasgow, vol. xv., 1912-13.

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consists in the inclusions being less highly crystalline. For example, a pitchstone with groundmass of glass and microlites shows the groundmass included in the phenocrysts either free from microlites or with a much reduced number of them. One oligoclase crystal showed rather peculiar inclusions, namely, perfect cubes of brown glass, each with a little gas bubble, which was usually situated in a corner. Unlike the quartz-porphyry, the pitchstone-porphyry regularly contains phenocrysts of two pyroxenes, one a green augite with 40 degrees extinction, and the other rhombic pyroxene with intense pleochroism. When the groundmass contains microlites they are found to be chiefly augites. Idiomorphic magnetite is a frequent constituent. Considering that this rock is merely a glassy facies of the quartz-porphyry so poor in ferro-magnesian minerals, it is difficult to account for the pitchstone containing not only pyroxene as phenocrysts, but having a groundmass heavily charged with pyroxene microlites. The same anomaly is found in the Arran pitchstones.

Basification of the Acid Rock.—The basification of the acid rock is entirely due to the digestion of xenoliths of the dolerite, and cannot be considered as either general in character or great in amount. As has been already indicated, basified rock cannot be well diagnosed from the hand specimen. Still, in general, it is found that sections cut from the junctions with xenoliths show basification, the indications being a large increase in the number of crystals of biotite and magnetite, augite fringes round the quartz grains, occasionally augite grains in the groundmass. These indications rapidly fall off with the distance from the xenolith, and sometimes normal rock will be found within an inch. In the case figured (Plate, Fig. 2) the acid rock is seen to have assimilated the pyroxene rim from half of the quartz xenocryst of the dolerite, but another part of the same slide shows a quartz phenocryst in the quartz-porphyry with a pyroxene envelope. In the pitchstone facies basification is shown by an increase in the amount of pyroxene and envelopes of green augite around the quartz. Thus the conclusion arrived at is that the basification is very limited in amount, and both irregular and restricted in occurrence.

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Relations of the Two Rock Types.—Comparing the mineral contents of the dolerite and quartz-porphyry, it will be observed that the differences are quantitative rather than qualitative. Quartz, plagioclase, monoclinic and rhombic pyroxenes, biotite, magnetite are common to both. Still, despite this coincidence, the field relations and the constant association of similar types elsewhere in the Tertiary province are sounder reasons for claiming consanguinity; for such minerals as are not common to all basalts and quartz-porphyries might be explained away as due to silicification and basification. In this connection it is felt that much more might still be got out of this ground by some additional work supported by chemical analyses.

Postscript (10th February, 1914).

Since going to press an analysis of the oligoclase has been made by A. Scott, M.A., B.Sc., and an analysis of the bostonite from the lenticle in the sill at Uamh Capuill has been made by A. Stevens, M.A., B.Sc. The analyses are appended.

	*Oligoclase.		Bostonite.
SiO_2	62·67	SiO_2	61·19
TiO_2	nt. fd.	Al_2O_3	14·20
Al_2O_3	22·48	TiO_2	1·83
Fe_2O_3	·70	Fe_2O_3	8·08
CaO	3·29	FeO	2·49
BaO	tr.	MnO	tr.
MgO	p.n.d.	MgO	0·50
Na_2O	9·62	CaO	1·74
K_2O	·41	BaO	tr.
Ll_2O	tr.	SrO	tr.
H_2O	·58	Na_2O	6·64
		K_2O	1·80
	99·75	H_2O-	0·47
		H_2O+	1·11
		P_2O_5	0·08
			100·13

*Analysis was made from a single oligoclase crystal from the quartz-porphyry, and all crystals contain inclusions of the groundmass.

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EXPLANATION OF PLATE XIV.

Fig. 1—Micrographic intergrowth of quartz and felspar in groundmass of quartz-porphyry. From upper acid sheet, W. of Glencallum Bay × 160.

Fig. 2—Junction of quartz-porphyry with xenolith of dolerite. The xenocryst of quartz has had part of its pyroxene envelope resorbed by the quartz-porphyry. From centre of lower acid sheet, Loch na Leighe × 10.

Fig. 3—Junction of colourless glass of the pitchstone-porphyry with dolerite xenolith. Note both in this and Fig 2 the sharp junction and the fine grain of the dolerite. From combined acid sheet, W. of Glencallum Bay × 10.

Fig. 4—Quartz xenocryst, with thick pyroxene envelope, from thick dolerite core, 8 feet from junction with lower acid sheet, Roinn Clùmhach × 40.

Fig. 5—Pitchstone-porphyry, showing large oligoclase in brown glass. Compare with Fig 3, which shows clear glass and numerous microlites. From combined acid sheet, W. of Glencallum Bay × 10.

Fig. 6—Quartz-porphyry, showing micrographic groundmass polarising in areas optically continuous. From upper acid sheet, where inner dolerite is very thin, W. of Glencallum Bay × 10. × nicols.

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No. XI.—A Composite Sill in Glen Cloy, Arran. By Alexander Scott, Jun., M.A., B.Sc., Carnegie Research Scholar of the University of Glasgow.

[Read 12th February, 1914.]

In the Geological Survey map of Arran a number of intrusions, designated variously as felsite, porphyrite, or basalt, are marked in Glen Cloy and its two tributary glens, Glen Dubh and Glen Ormidale. The obviously composite nature of one of these and the rather remarkable appearance of the rocks suggested that the occurrence would repay more detailed examination. The intrusion in question is a sill occurring in the bed of the stream in Glen Cloy at a point about 300 yards E.S.E. of the house of High Glen Cloy. The sill is intruded along the bedding-planes of the Lower Triassic sediments which here dip to the S.S.W. at an angle of 20°, and it is exposed for a distance of about 12 yards. The total thickness is approximately 12 feet, and as the Triassic conglomerate is exposed in contact with both the top and bottom of the intrusive rock, this represents the true thickness of the sill.

The greater part is a dark grey rock, which has a well-developed columnar structure, together with subsidiary horizontal jointing. The rock is a felsite of aphanitic appearance, the only minerals macroscopically visible being felspar crystals, arranged generally in groups. The appearance of the rock is not uniform, as it is traversed by bands, of a reddish colour, and about $\frac{3}{4}$ of an inch in width, the colour being due to the presence of innumerable minute patches rich in iron oxide. Elsewhere an apparently spherulitic structure is assumed, the surface being covered with white spots up to a millimetre in diameter.

Overlying this, and generally separated from it by a joint-plane, is another intrusion, the thickness of which is about 12 inches. It is a black rock of flinty appearance, with isolated porphyritic felspars, and traversed by numerous veins of quartz and calcite. On the south side of the burn the two rocks can be seen in contact, the line of junction being perfectly sharp and

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well defined. At the upper surface of this black rock its appearance gradually becomes more glassy, and finally it passes to a black lustrous pitchstone, the thickness of which varies up to 4 or 5 inches. This shows the same porphyritic minerals as the black rock, and apparently differs from the latter only in the glassy nature of the groundmass. It also contains, occasionally, inclusions of the overlying conglomerate.

The Glen Cloy pitchstone included in the list in the Geological Survey Memoir,[1] and described in detail by Harker,[2] does not refer to this rock, but to one which occurs on the hillside 300 yards S.E. of the locality mentioned above. In the small wood to the north-east of Kilmichael, and situated midway between those two localities, another pitchstone is indifferently exposed in a small burn. This is a glossy, coal-black rock, with subconchoidal fracture, but the occurrence is so much obscured that only about a foot of it can be seen, and nothing can be ascertained regarding its relations to the surrounding rocks. As it shows some resemblance, microscopically, to the other occurrences, it will be described with them.

Microscopic Characters.

In thin section, the lower rock of the composite sill is seen to consist of phenocrysts of felspar and a ferromagnesian mineral in a cryptocrystalline groundmass. The felspars are generally replaced by calcite to such an extent that exact determination of their nature is difficult. The rare unaltered crystals show an exceedingly fine lamellar twinning, with occasionally subsidiary striations following the pericline law. The majority of the crystals seem to be an acid andesine, but a few, with very fine twinning and low refractive index, may be anorthoclase. The ferromagnesian mineral is now largely represented by chlorite, but the form and unaltered traces suggest that the original mineral was augite. In addition there are numerous microlites in the form of small rectangular skeletons, but entirely replaced by chlorite and iron-ores. Other patches rich in the latter suggest a secondary segregation of these pseudomorphs.

[1] "Geol. of N. Arran, &c." (*Mem. Geol. Sur., Scotland*), 1903, p. 94.
[2] *Ibid.* pp. 125-126.

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The groundmass varies in different parts of the sill, but the variations are quite irregular. In general it is a crypto-crystalline aggregate of felspar with subordinate quartz and permeated with finely divided ferric oxide. In certain parts, which are generally poor in microlites, the structure is so typically spherulitic as to suggest that the crystallisation took place during the process of cooling. This is particularly the case in the "spotted" rock, where the groundmass consists of well-developed spherulites, and microlites are practically absent. In the main, however, the great abundance of microlites and the very irregular areas of the groundmass, which are in optical continuity, indicate that the crystallisation is probably the result of devitrification.

As the black rock of the upper sill is obviously the devitrified representative of the pitchstone, it will be more convenient to describe the latter first. The only porphyritic crystals are felspar and pyroxene, which are perfectly unaltered, and tend to occur in glomeroporphyritic aggregates. The felspar occurs in subhedral crystals with good Albite and Carlsbad twinning, and has the optical properties of andesine. The crystals are generally traversed by a series of cracks, and large inclusions, often of the same external shape as the crystal, are common. The pyroxene occurs as yellow-green elongated crystals with slight pleochroism. The crystals are often broken into granular aggregates, the optical properties indicating augite with some admixture of aegirine. The microlites show an irregular fluxion arrangement, and exhibit considerable variety of form, though the different types grade into one another. The largest are augitic belonites with the usual bifurcating ends, while the intermediate ones are skeletal growths, with one axis much more developed than the others. Subordinate to these in size are innumerable greenish longulites, often apparently orientated with respect to the skeletal microlites. The glass is probably colourless, but it is rendered apparently brown by the great abundance of longulites. Small spherulitic areas are found round partly resorbed crystals of felspar. Occasionally the skeletal growths are absent, in which case there is a corresponding increase in the number of longulites.

The main rock of the upper sill is obviously the same as the

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pitchstone, save that the groundmass is crystalline. The phenocrysts are likewise andesine and augite, but are very much decomposed, while the belonites are replaced by chlorite and limonite, and the longulites by disseminated iron-ores. The remainder of the groundmass is made up of the usual irregularly polarising aggregates, and is apparently composed chiefly of felspar. Both rocks show evidence of shearing, partly by the cracked crystals of felspar and partly by certain irregular banded structures in the groundmass.

Where the two rocks are in contact certain peculiar microstructures are seen. A narrow band of the lower rock along the contact plane is more definitely crystalline than the rest of the rock, and shows less evidence of devitrification. There is the same great abundance of microlites, however, but the groundmass also contains some elliptical spherulitic areas which are practically free from the microlitic growths. As the actual junction is approached these tend to have the felspathic minerals replaced by limonite, and finally the microlites disappear, the junction rock consisting wholly of these limonitic areas in a groundmass saturated with the same material, which in this case probably arises from the decomposition of longulites. No such structures occur in the upper rock, which appears, even under the microscope, to remain unaltered right up to the fairly sharp boundary between the two rocks.

The rock which is exposed in the Kilmichael Wood is composed of porphyritic crystals of zoned felspar—andesine—and yellow-green augite in a microlitic base. The phenocrysts are small and somewhat scarce. The microlites, which are present in great abundance, are skeletal growths elongated in one direction, while in the interspaces are numerous subsidiary outgrowths perpendicular to the skeleton axes. The glass itself is perfectly clear and colourless, and the whole rock is quite free from devitrification or alteration of any sort.

The rock which occurs further up the hillside has been described by Harker[3] as probably a pitchstone which has undergone devitrification and other changes. A comparison of slides of it, kindly lent by the Geological Survey, with those of the Glen Cloy rocks, shows that it is practically identical with the

[3] **Harker**, *loc. cit.*

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lower rock of the composite sill in appearance. As this sill is dipping S.S.W., and the former rock outcrops at a place a little north of east of the sill-outcrop, and at a greater height above sea-level, the two rocks are approximately on the same stratigraphical horizon, and this, combined with the lithological similarity, renders it possible that they belong to the same intrusion.

Petrology and Relations of the Two Rocks of the Sill.

The lower rock for the most part shows signs of great alteration. The phenocrysts, from their size and glomeroporphyritic habit, must have formed under plutonic conditions. The form and size of the microlites indicate the conditions of their formation. In the case of a salt dissolved in water, skeletal crystals tend to form if the evaporation of the solvent is rapid or if the degree of solubility is low, that is, if the tendency for the solution to become supersaturated is great. Similarly, high viscosity is another favouring condition. The groundmass of this rock must have cooled fairly rapidly to a comparatively low temperature before crystallisation took place. The large number of separate skeletons indicate that it did commence in the metastable region and probably near the metastable limit. By this time the magma must have been highly supersaturated with respect to the ferromagnesian molecules, the amount of which is shown by the comparative abundance of the microlites. The viscosity must likewise have been very high, as the skeletons are the rectilinear ones indicative of a low degree of mobility, and differing from the curved forms more usual in the Arran pitchstones. The residual material, which had been acting as solvent, probably first reached ordinary temperatures as a glass. The spherulitic portions, however, crystallised during the process of cooling, since large spherulites such as these are probably never the result of devitrification.[4] The upper rock had a cooling history very like that of the lower. The occurrence of several different forms of microlites indicates that the crystallisation continued over a greater tempera-

[4] Harker in "Geol. of Small Isles" (*Mem. Geol. Sur., Scotland*), 1908, p. 181.

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ture range. The belonitic forms developed fairly high up in the metastable region, but rapid cooling, combined with the greater content in ferromagnesian material, increased the degree of supersaturation and viscosity to such an extent that skeletal forms began to appear. The cooling was apparently too rapid for the separation of all the solute in these forms, and the remainder crystallised as longulites at a still lower temperature, probably in the labile region. The whole of the ferromagnesian material seems to have crystallised out before atmospheric conditions were reached, as there is no evidence, either in the colour of the glass or in the products of devitrification, of the presence of iron or magnesium-bearing molecules in the groundmass. The latter finally consolidated as a glass, but throughout the greater portion of the sill this has undergone subsequent devitrification.

It is rather difficult to determine the relative ages of the two sills. The probability is that the lower was the first to appear, but that the upper was intruded not long afterwards. The significant phenomena are—

(*a*) The lower rock becomes more definitely crystalline as the junction is approached.
(*b*) The microlites of the lower rock become more decomposed, and the number of segregated patches of limonite increases near the contact.
(*c*) The upper rock shows no structural difference near the contact.

The first two of these may be taken as evidence of some degree of re-heating, which would not only allow the groundmass to crystallise in a more definite fashion, but would also involve the alteration of the microlites through oxidation, &c., and the partial segregation of the iron oxides thus produced.

The only argument against this is the presence of the pitchstone on the upper surface of the top rock. This glassy portion, however, is probably of the nature of a chilled margin, from which the various mineralisers escaped, thus rendering this part less liable to devitrify on account of the high viscosity. This would also act as an impermeable envelope, which would prevent the escape of gases from the rest of the rock, and hence allow the

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latter to have a greater chance of devitrifying owing to the lower degree of viscosity.

On the whole, the evidence shows that the crystallisation of both rocks from a glassy condition ensued merely as a matter of course, just as any highly supersaturated and undercooled solution will crystallise if given long enough time. The chance of devitrification is probably increased by the absence of free silica (siliceous rocks show, in general, less tendency to crystallise than more basic ones), and by the comparatively high percentage of ferromagnesian molecules and of water (shown by the great amount of limonite). The crystallisation of the lower rock has not apparently been aided by the heat of the other intrusion unless in the narrow microcrystalline band along the plane of contact.

Although no analyses have been made of these rocks, it is possible to assign their petrological affinities with some degree of accuracy. The only identifiable minerals are felspar, which is chiefly andesine, and augite, and the great abundance of the latter would indicate that they belong to the more basic andesites, the upper rock being slightly the more basic of the two. Judd has described the Cir Mhor[5] dyke and the pitchstone of Beinn Hiant, Ardnamurchan,[6] as augite-andesites. As far as can be judged from the appearance in thin section, the former is much more acid than the rocks here described, while the latter is certainly not more basic. Indeed the Beinn Hiant rock contains quartz-phenocrysts, while the quartz in the Glen Cloy rocks is probably all of secondary origin.

The Kilmichael pitchstone shows certain intrinsic differences from those described above. The cooling history is much more simple. The phenocrysts, as usual, are of plutonic origin, while the nature of the microlites, which are practically all of one type, indicates that their formation took place in a fairly viscous magma. They began to crystallise in the metastable region, but the high degree of supersaturation caused the formation of comparatively large skeletal growths. There is no evidence whatever of subsequent crystallisation in the labile region or of devitrification. This rock is probably more basic

[5] *Q.J.G.S.*, 1893, xlix., pp. 536-566.
[6] *Q.J.G.S.*, 1890, xlvi., pp. 341-385.

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than any of the Arran pitchstones hitherto described. Although it is difficult to make an exact estimation, probably 40 per cent. of the groundmass is composed of the pyroxene microlites. Hence the rock may be classed as a basic andesite in composition.

Despite some lithological similarities, the greater amount of augitic material and the extraordinarily unaltered state of the rock render it improbable that the Kilmichael occurrence is another outcrop of the sill. It seems to be another dyke or sill, which, however, belongs to the same series as the Glen Cloy intrusions. Apparently there is a series of pitchstones in and around the great Tertiary Vent which differ essentially from the other Arran pitchstones, and form a group by themselves. Thus an examination of slides of altered pitchstones from the district round Ard Bheinn shows these rocks to be very similar to the devitrified ones described above. Again, a granophyre sill in Glen Dubh contains xenoliths of a pitchstone closely resembling the Kilmichael rock. This group is more basic in composition than the other Arran glasses, and seems to be connected with the activity which produced the diorites and dolerites of the Vent. If so, they must have been intruded at a comparatively early period in the sequence of Tertiary activity. Judd[7] has placed the Cir Mhor dyke as fairly late in the Tertiary volcanic period, while the more acid pitchstones probably represent the last phase of igneous activity in this region. The Glen Cloy rocks are probably earlier than any of these, and seem to be earlier than the acid sills of the Vent, since they occur as xenoliths in the latter.

In Glen Dubh and Glen Ormidale the felsites and granophyres are intrusive into the basic rocks, and hence are younger than the latter. There is no direct evidence of the relative ages of the Glen Cloy pitchstones and the diorites, but the probability is that the latter are the earlier, and that the former succeeded them, just as the pitchstones in the south end of the island succeeded the later basic rocks.

Note on the Pitchstone-Porphyry of Glen Shurig.

This intrusion occurs in Glen Shurig about "half a mile west of the church, in the road leading down to the highest

[7] Judd, *loc. cit.*

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house in the glen."[8] The exposure is so much obscured by vegetation and drift material that it is difficult to say whether it is a dyke or a sill, the probability being that it is the former.

The rock is dark green in colour, with conchoidal fracture and a "pitchy" lustre, while the only minerals visible in the land specimen are minute crystals of quartz and felspar.

Microscopically the rock consists of a great abundance of porphyritic minerals in a glassy groundmass. The former comprise quartz, felspar, pyroxene, olivine, and magnetite. The quartz crystals never show the original faces, but are the corroded anhedrons usual in this type of rock. The felspar is mainly euhedral plagioclase, exhibiting both Albite and Carlsbad twinning. The crystals are finely zoned, the basicity decreasing progressively from the centre to the periphery, and the compositon varying from oligoclase-andesine to a fairly acid oligoclase. Rectilinearly orientated inclusions, consisting of small cuboid patches of groundmass are common,[9] while occasionally much larger ones, generally in the form of negative crystals, occur. There are two kinds of pyroxene, one an augite, with an extinction angle of about 30°, and probably containing some aegirine, and the other a green pleochroic enstatite. Olivine occurs in rounded crystals, greenish yellow in colour. This, combined with the very high double refraction, would indicate a high content of the fayalite molecule. It alters to a mesh arrangement of a reddish translucent mineral resembling iddingsite.

The phenocrysts occur in glomeroporphyritic aggregates, and these may be divided into two classes. One type has abundant quartz and felspar, with subordinate pyroxene, while the other is quartzless, and consists of felspar, pyroxene, and olivine. One of the latter type contains no interstitial glass, but is holocrystalline, consisting of about a dozen large felspars surrounding a group of smaller crystals of plagioclase, pyroxene, and scarce olivine. Considered apart from the rest of the rock, this would be described as a gabbro.

The groundmass is composed of two generations of microlites in a clear glassy base. The former are chiefly green non-

[8] "Geol. of N. Arran, &c." (*Mem. Geol. Sur., Scotland*), 1903, p. 94.

[9] *Cf.* Smellie. *Trans. Geol. Soc., Glasgow*, 1914, xv., p. 136.

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pleochroic belonites with the same extinction, and apparently of the same composition, as the augite phenocrysts. There is a continuous gradation in size from the microlites to the porphyritic pyroxenes. Subordinate to these are a number of minute longulites, which make the glass apparently yellowish in colour. The interstitial groundmass is the glomeroporphyritic aggregates, and also that in the larger inclusions contains microlites of a different type. The larger microlites are fewer in number, and generally show complicated cruciform or arborescent structures where there is a greater density of longulites.

This rock bears some resemblance to the other olivine-bearing pitchstones of Arran, the Loch na Leirg and Burican occurrences,[10] as well as to the pitchstone-porphyry of South Bute.[11] It differs from the last of these, as from the Beinn Hiant,[12] and the Strathmore[13] (Skye) rocks, which it structurally resembles, in the presence of olivine. The explanation given of the occurrence of the latter mineral in the Burican rock[14] satisfies this present case also. The rock is undoubtedly too high in silica for any olivine to appear in the norm, and this, combined with the grouping of the phenocrysts into two types of aggregates, suggests that those of one type at least are of xenocrystic origin. It is most probable that the more "basic" aggregates are xenolithic, as the groundmass is too highly siliceous for these to have crystallised directly from it.

The Glen Shurig rock, however, differs from the olivine-bearing rocks mentioned in the total absence of devitrification, while it does not show the same variety of microlites. While the rapid fall to ordinary temperatures has occurred before all the femic material could crystallise as phenocrysts, the temperature-gradient has been low enough to allow it all to crystallise in one form or another before the solvent became very viscous, except where, in the neighbourhood of the felspar crystals, the skeletal forms indicate a higher degree of viscosity.

[10] Scott. *Trans. Glas. Geol. Soc.*, 1914, xv., pp. 16-37.

[11] Smellie, *loc. cit.*

[12] Judd, *loc. cit.*

[13] "Tert. Igneous Rocks of Skye" (*Mem. Geol. Sur., Scotland*), 1904, p. 405.

[14] Scott, *loc. cit.*, p. 29.

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which may possibly be due to the temperature being locally lowered by the xenocrysts. The comparatively uncorroded margins of a mineral such as olivine, which is easily soluble in siliceous magmas, indicate a fairly low temperature in their neighbourhood. This lowering of the temperature would cause a break in the sequence of crystallisation of the ferro-magnesian material, which would then come out of solution under higher viscosity, first as the skeletal forms, and finally, as the temperature became low, as longulites.

On the whole, this rock is a typical member of the series of pitchstone-porphyries which are intrusive into the rocks of the south end of Arran. Although pitchstones with porphyritic crystals occur further north, notably on Cir Mhor and Caisteal Abhail, these rocks contain no olivine and very little pyroxene, and the Glen Shurig intrusion may be taken as one of the furthest outlying members of the Tighvein group.

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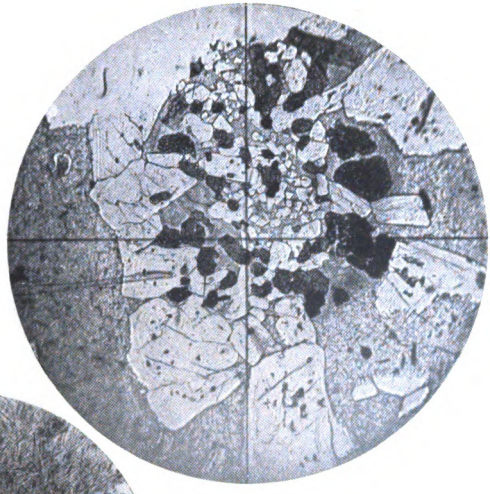

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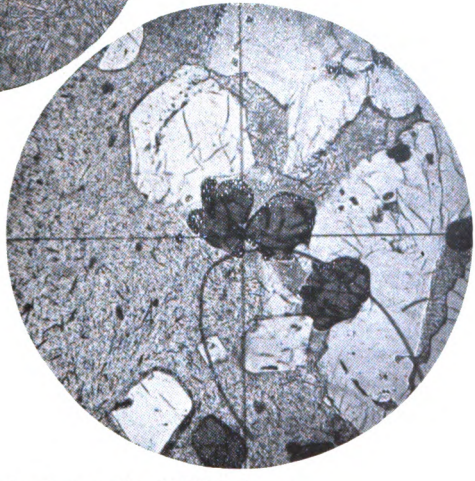

No. 3.

Photomicrographs of Pitchstones.

No. 1. Glomeroporphyritic aggregate in Glen Shurig Pitchstone. Comprises crystals of labradorite, augite, enstatite, and olivine. In ordinary light. x 30.

No. 2. Groundmass of Kilmichael Pitchstone, showing abundance of skeletal microlites. x 30.

No. 3. Phenocrysts of olivine and felspar in Glen Shurig Rock. Shows different forms of microlites in groundmass between crystals. x 30.

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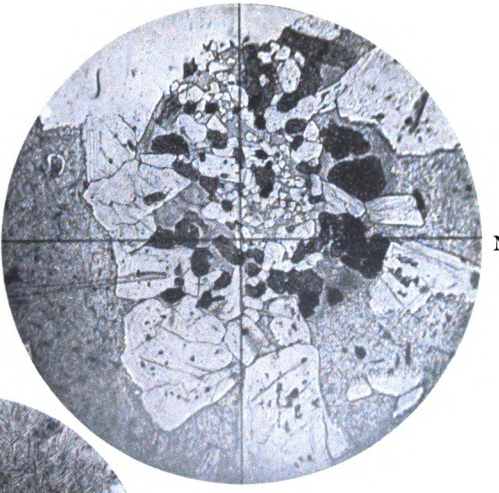

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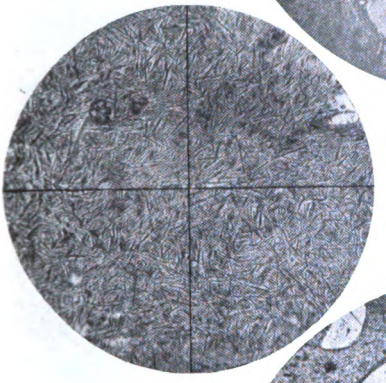

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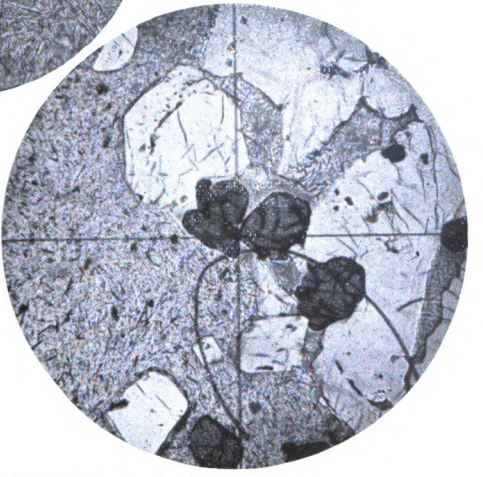

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No. XII.—The Carboniferous Sediments around Strathaven.

By R. G. Carruthers, H.M. Geological Survey.

[Read 12th February, 1914.]

The uplands of Lanarkshire are of abounding interest to the field geologist; they have long afforded material to both amateur and professional, so that certain parts may be regarded as classic ground. Of the less-known portions one of the most interesting is certainly the triangular area of Carboniferous rocks between Limekilnburn, Stonehouse, and Strathaven; nevertheless, apart from the Geological Survey maps and Explanation (Sheet 23), no publications dealing with this ground seem to have appeared; the paper now presented is the result of revision work carried out for the Survey in the autumn of 1912.

The strata in this region lie on the south-western fringe of the great Lanarkshire coalfield; they range from the base of the Coal Measures down to the Calciferous Sandstone Series, so that all the more important members of the Lower Carboniferous rocks are present, although one must confess that they are developed in an attenuated form.

Broadly speaking, these strata are divided into four distinct areas[1] by a series of step faults, all with a downthrow to the north, and with a general direction east by south. It thus follows that the highest strata are let down in the most northerly of these fault blocks, namely, that in the Crookedstone district, between Limekilnburn and Darngaber Castle.

Within the Crookedstone fault block the strata as a whole are inclined at a very gentle angle to the south-east. The lowest horizon may be taken as the band of limestone running through the hamlet of Limekilnburn; as this limestone has been extensively quarried in past times, the line of outcrop is easily

[1] The chief interest attaches to the most southerly of these, and with that alone is the map accompanying this paper concerned. The existing Geological Survey 1-inch map (Sheet 23) gives an approximate idea of the other three areas.

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followed, but there is a corresponding difficulty in getting a view of the seam itself. The best exposure is on the south bank of the stream 700 yards due west of Quarter Road railway station; here the limestone is seen to be 4½ feet thick, with a ½-inch parting of blaes in the centre; it is a hard, pale grey stone, with porcellanous fracture and creamy weathering; fossils are scarce, but a few small brachiopoda and crinoid ossicles can be seen. Further down stream, immediately below the bridge at the keeper's cottage, a fault of 10 feet or so throws up the underlying strata, and at the top of the bank one can see that the limestone rests on blaes with brachiopods, &c., under which is an 8-inch bed of dark, slaty blaes lying on 4 inches of foul coal with fireclay below; at this point, in the dark slate above the coal, Mr. Tait has collected specimens of *Edmondia punctatella*, the characteristic index fossil of the Calmy or Gair Limestone position. This recognition of the Limekilnburn Limestone as the Calmy is confirmed by other evidence; a deep boring by the Shotts Iron Company on the north side of the stream 400 yards west of Browntod, started at the outcrop of the Limekilnburn Limestone, met the Orchard Limestone with its characteristic blaes at 18 fathoms, and passing through the Index Limestone (6 feet 8 inches thick) at 47 fathoms went on through the Coal and Ironstone group below, ending in the Lesmahagow Gas Coal position (Crutherlands Coals of East Kilbride) at 97 fathoms.

In the stream passing under the main road south of Limekilnburn some 30 feet of blaes, with two thin bands of limestone, can be seen. These strata lie immediately above the Limekilnburn Limestone, and are of interest because they contain occasional crushed specimens of Clisiophyllid corals, fossils which are, as a general rule, exceedingly rare in the Upper Limestone group in Scotland. Higher strata ranging up to the Coal Measures are exposed further downstream east of Browntod; here there is a gently undulating sequence of sandstone, blaes, and fireclay. About 750 yards east of Browntod a thin band of parroty coal and blaes with *Lingula* crosses the stream, and a few yards lower down there are excellent exposures of a hard, ochreous weathering, blue grey limestone containing a few small crinoid ossicles. Since the field evidence shows

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that this limestone lies between the Calmy Limestone of Limekilnburn and the slaty ironstone of Darngaber, it may be taken to represent the Castlecary Limestone, a seam now recognised as marking the dividing line between the Upper Limestone group and the Millstone Grit. This identification is of considerable interest, because until the recent revision by the Geological Survey no representation of the Castlecary Limestone had been recognised on the south side of the Lanarkshire coalfield.

Just before the road bridge is reached a small fault throws off the limestone, and the "parrotty blaes" below is brought up to the top of the cliff; this horizon reappears further downstream, where it can be traced along the top of the bank for several hundred yards, until it gradually comes down to the stream level opposite Darngaber. Here a small fault brings down a coarse, pebbly sandstone, not hitherto seen, and which one may therefore regard as lying above the Castlecary Limestone, or, in other words, belonging to the Millstone Grit. Some 30 yards east of the Darngaber footbridge the stream section shows that the base of the grit lies 20 feet above the "parrotty blaes"; the Castlecary Limestone ought to come between these positions, but no trace of it can be seen. As there is no room for faulting, one may infer that the limestone has been cut out by an unconformity of the pebbly sandstone, and closer inspection shows that the base of the grit (seen on each side of the footbridge) is evidently transgressive on the underlying strata.[2]

Below Darngaber the Coal Measures are faulted down against the Millstone Grit, but the missing strata can be picked up without difficulty in the stream to the south. Old workings in the Slatyband Ironstone (the basal bed of the Coal Measures) can be traced on each side of the stream west of Darngaber Castle, and on the south bank, 400 yards west of the site of the castle, there is an excellent exposure of the ironstone halfway up the bank. Field exposures of a Slaty Ironstone are few and far between, such a valuable mineral having, as a rule,

[2] The evidence of a discordant junction at the base of the Millstone Grit is not perhaps very strong; the unconformity may, however, be accepted as a fact owing to the convincing sections illustrating this point in the gorge of the river Avon above Larkhall, a few miles to the east.

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been entirely removed; the section may therefore be given in detail as follows:—

Soft yellow freestone, rather coarse, - -	20 ft. seen.
Soft grey blaes with balls of clay ironstone,	3 ft. 6 ins.
Slaty ironstone (striped, with coal films; the top is nodular, and there is a ½-in. to 4-inch pyritous rib at the bottom).	
Fireclay, - - - - - - - - -	3 ft. 5 ins.
Fakes and sandstone ribs, - - -	5 ft.
Soft yellow sandstone, with many coarse pebbly beds (Millstone Grit).	

The presumption that in this district the Millstone Grit is represented by a coarse pebbly sandstone is confirmed by sections further upstream, where the Slaty Ironstone is seen to be underlain by some 40 feet of coarse yellowish sandstone; beneath the grit a limestone, identical with that referred to the Castlecary in the Darngaber Burn sections, can be seen in the bed of the stream 400 yards N.W. of Crookedstone Farm. Farther south a reversal of dip once more brings down the grit, above which, at a bend in the stream due west of the farm, another section of the Slatyband is seen; the seam is very thin here, being represented by 4 inches of slaty blackband and parrotty blaes with *Lingula*, cut off to the south by a fault of 15 or 20 fathoms, bringing up strata beneath the Gair or Calmy Limestone. This dislocation marks the southern boundary of the Crookedstone fault block, and can be traced westwards to the stream south of Limekilnburn, where an impure limestone and coal in the Lyoncross position are brought up against the Calmy Limestone.

The fault block south of Crookedstone is long and narrow, having an average breadth of about 500 yards. The chief feature here is the Calmy Limestone, which appears in two shallow synclines north and east of Crookedstonemuir Farm. The limestone has been almost entirely quarried away, but is still visible by the side of the burn due east of the farm; the section agrees with that of Limekilnburn, and the "*Edmondia* slate" is particularly well seen on the west bank, although fossils are very

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scarce. To the south a couple of faults cross the stream with a downthrow to the north; they are but a few yards apart, and between them can be seen a grey crinoidal limestone with ochreous weathering resting directly on 6 feet of soft sandy blaes. This limestone may possibly represent the Index, with which it agrees best in character. The fault on the south side of the limestone must be a large one, perhaps 70 fathoms, for the beds upstream dip to the south, and 500 yards S.E. of Crookedstonemuir Farm a limy band appears, which can be correlated beyond doubt with the "Johnstone Shell Bed"[3] or Slingstane Limestone of Carluke. The sequence of fossils characteristic of this position is well seen, the section being—

Clayband ironstone crowded with small lamellibranchs and many *Lingulæ*, a few small *Producti*, fish teeth, and gasteropods, - - - - -	4 ins.
Black slaty blaes, crowded with *Lingula*, -	1 ft. 6 ins.
Soft micaceous blaes, with abundant small *Productus* and crinoid ossicles, - -	3 ft.
Hard encrinital limestone, - - -	7 ins.

About 70 yards upstream a reversal of dip, accompanied by a small fault down N. brings up a seam of coal, lying about 20 feet below the Shell Bed. The seam has been worked out at the outcrop; in the year 1912 trial workings proved it 20 inches thick, but the area available must be very small, the syncline being only about 25 acres in extent. A mile to the east another exposure of the Shell Bed can be seen in a drain 400 yards south of Airybog, and also to the S.W. of Burnbank; these exposures are of value, because they fix the approximate stratigraphical position of the great sheet of dolerite stretching from Heads to Nethershields; in the drain section south of Airybog the base of the dolerite is seen resting directly on the Shell Bed.

Few observations on the Shottlinn fault block can be made other than those above detailed. It may, however, be noted

[3] This horizon, the index to the Johnstone Clayband position, is only 20 fathoms or so above the Top Hosie Limestone, so that almost the whole of the Middle Limestone Coal Group is thrown out by the fault.

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that in the railway cutting north of Glassford Station glacial cross-striæ are clearly seen on the dolerite sill, here containing inclusions of burnt coal and blaes; the directions are E. 26° S. and E. 27° N., the latter apparently being the latest. The southern boundary fault is never seen at the surface, and its existence is inferred on account of the presence of Calciferous and Lower Limestone sediments over a large area south of West Quarter. It is this region which is of paramount interest to the geologist, and on this account is worthy of an extended description.

In the river Avon and its tributaries, to the N.E. of Strathaven, there are excellent sections of some 80 fathoms of strata, ranging from the Calderwood Cementstone down into the Calciferous Sandstone Series (Plate XVIII.). The finest exposures are undoubtedly those seen along the river around Cot Castle, where a gentle anticlinal fold brings up Calciferous sediments, flanked by members of the Lower Limestone group (Plate XVI.). The higher beds (Hosie Limestones) are visible in two small burns on the south side of the river, running down from the farms of Crumhaugh and Lounsdale respectively. In the Crumhaugh Burn the Calderwood Cement can be seen at the top of a low bank 400 feet south of the railway; it is represented by a 9-inch band of grey calmy limestone, with calmy blaes above and below, full of *Lingula* and *Posidonomya corrugata*. Below this are 3 feet of "shelly blaes," under which is the position of the First Kingshaw[4] Limestone, here quarried away. It is of interest to note that in the floor of the First Kingshaw there is a 2-inch red iron rib exactly as in the East Kilbride country. A small fault in the stream throws up the Second Kingshaw Limestone, which is hard and crinoidal, and can be seen 3 feet below the "red rib." Further downstream is the Birkfield Limestone, here somewhat irregular, 1 to 2 feet thick, red weathering, and with large encrinites, as at Carluke and East Kilbride.

A duplicate section is seen to the east, in the Lounsdale Burn, where the Cement is visible, but the two Kingshaw Limestones

[4] The nomenclature of limestones in this paper follows, as far as possible, the long-established sequence of Carluke, which may be accepted as the standard for the South Lanarkshire field.

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have been quarried away, although the Birkfield can be seen a few feet above the road bridge. The underlying strata are seen to much greater advantage than in the Crumhaugh stream section; 10 feet of blaes is seen under the Birkfield, and then comes a 6-inch band of limy ironstone full of entomostraca (this horizon also can be paralleled at East Kilbride). Below the limy ironstone are some 20 feet of blaes with clay ironstone balls, and then a hard crinoidal limestone outcrop, on which the main road bridge is built. This is the "Foul Hosie" Limestone of Carluke, and is underlain by yellowish fireclay. A little further downstream the Main Limestone appears, but the section is poor compared with those further up the river, to which attention will subsequently be directed.

Turning now to the river sections, the three chief limestone positions ("Foul Hosie," Main, and Under Limestones) all cross the stream round the bend 500 yards below Cot Castle. On the east bank the Foul Hosie and Main have both been quarried out, but an excellent section of the Under Limestone can be seen. As this is the only good section known in the district, details are given below:—

	Ft.	In.
Yellow fireclay and ribs of green kingle sandstone, -	6	—
Flaggy sandstone and fakes, - - - - - -	5	—
Soft sandy blaes (rootlets), - - - - - -	1	—
Red weathering crinoidal *Limestone*, - - 3 to	—	6
Blaes parting, - - - - - - - - - -	—	4
Grey crinoidal *Limestone*, bright yellow weathering, contains a few small *Producti*, &c., - - - -	1	9
Soft limy blaes with *Productus*, &c., - - - - -	2	—
Dark slaty blaes with ferns* and a few small *Naiadites*, *Lingula*, and fish scales, - - - -	—	3
Hard rib of siliceous grit with fish teeth and scales, -	—	½
Coal, - - - - - - - - - - - -	—	½
Coaly fireclay, - - - - - - - - - -	—	4
Sandy fireclay, - - - - - - - - - -	3	—
Kingle Sandstone with fireclay partings.		

* Dr. Kidston refers one of these to *Sphenopteris decomposita* Kidst, remarking that "it is identical with specimens from the Oil Shales at West Hermand, West Calder . . . the type of the species is from Glencartholm." This observation is of great interest, as it carries the Calciferous flora up to the Under Limestone in this district, confirming Dr. Kidston's well-known view that the dividing line between the Calciferous and Lower Limestone floras occurs about the Hurlet (=Main) Limestone position—a strong palæontological support for the existing lithological classification used by the Geological Survey.

A small fault running along the bed of the river throws the Under Limestone of the above section against the Main, the latter appearing on the west bank with the Under Limestone

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below. Further upstream the section has been partially covered up with the débris of old ironstone workings, but above the bend a magnificent cliff section appears on the east bank (Plate XVI.). The strata in this great cliff are practically horizontal; they all lie below the Under Limestone above described, and are therefore well within the Calciferous Sandstone series, a fact adding greatly to their geological interest.

The full sequence, measured from the top of the cliff down to the river, is about 120 feet altogether, and is given, along with other strata, in the graphic sections accompanying this paper (Plate XVIII.).

The "Tree" Coal[5] of this section runs along the upper part of the cliff, beneath the sandstone escarpment. The seam is only a foot thick, and much of this has been quarried away.

The "Basket Shell Bed," which is the chief feature of interest in the section, is well exposed at the south end of the cliff; it is in the main a "limy blaes" full of brachiopoda and common marine fossils, indifferently preserved. In the topmost part there is an inch or two of hard dark blaes full of crushed goniatites and fine examples of the rare lamellibranch *Posidonomya becheri*, a shell also found in a similar sediment in the floor of the seam, immediately above the Blackband Ironstone; the ironstone has been mined away all along the river front, but can still be seen round the corner just above the Lounsdale Burn, and again on the west bank of the river 450 yards N.N.W. of Cot Castle; at the former locality the *becheri* shales resting directly on the Blackband abound in a small *Productus* with exceedingly fine ribs, considered by Dr. Ivor Thomas to represent a new species.

A fair number of ferns can be got in the *becheri* portion of the shell bed, but the Cot Castle exposure has not yielded quite such a good list as that obtained from the original locality in Calderwood Glen near Basket Farm. (See list appended.)

The cliff at Cot Castle is terminated by a 20-fathom fault, trending east by south, which brings down the Limestone

[5] So named because a large upright "fossil tree" can be seen in the cliff face, resting on the coal; in 1912 the stigmarian rootlets could be seen spreading out over the coal, but on a recent visit (May, 1914) part of the trunk had slipped down, crushing the roots out of place.

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Measures to the south. Mention has been made above of the limestone section seen in the Lounsdale Burn, and attention may now be turned to the river section. The Under Limestone is found in the river bed at Cot Castle, on the south side of the fault, while the Main or Hurlet Limestone runs horizontally along both sides of the river nearly up to Glassford Bridge. Much of this limestone has been quarried away, and it was at one time sufficiently valuable to be worth mining to a small extent. Good exposures can be seen on the north bank of the river, where 5 feet of solid limestone can be seen resting on an inch or so of foul coal; the distinctive feature of this limestone is the presence of *Lithostrotion junceum* and occasional clisiophyllid corals.

Over the limestone there are 10 to 20 feet of blaes, quite barren of marine fossils, but containing fragmentary plant remains, and also a seam of coal, of which few traces can now be seen, as it has been worked out along the outcrop. This coal was reported to be about 2 feet thick when found in building the foundations for the Glassford Bridge. It is on the same horizon as the "Wilsontown Smithy" Coal of S.E. Lanarkshire.

An irregular bed of hard limy sandstone (with annelid burrows at Cot Castle) overlies the coal, and on this rests a 5 or 6 foot fireclay capped by the Foul Hosie Limestone. The limestone is very poorly exposed at the top of the river bank 330 yards east of Glassford Bridge; a few zaphrentid corals (the distinctive fossils of this horizon) can be seen, but the Neilson Shell Bed is cut out by the boulder clay covering. For good sections of the Foul Hosie and its associated strata recourse must be had to the exposures further up the river near Waulkmill.

There are two sections of the Foul Hosie in the river—one is at the sharp bend half a mile east of Waulkmill, the other close to the farm and near the railway. Of these, the last-named is much the best, old workings having obscured much of the sections elsewhere. The limestone can be seen on either side of the river, while on the north bank there is an excellent exposure of the Neilson Shell Bed, that highly fossiliferous shale which forms such a characteristic covering to this limestone round Glasgow and in South Lanarkshire generally, and affords

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so striking a contrast to the barren shales that rest on the Main or Hurlet Limestone. *Euomphalus*, *Dentalium*, small gasteropods, brachiopoda, &c., occur here in profusion and in excellent preservation. The shale is, however, of a tender and friable character, and the fossils require great care if they are to be carried away intact.

The other exposure, half a mile east of Waulkmill, although poor, is of interest, because traces of the overlying Hosie Limestones can be seen in the river bed in the vicinity, and there is little doubt that they occupy a shallow synclinal fold to the north and south.

South of Waulkmill the Main or Hurlet Limestone, with its characteristic *Lithostrotion* corals, crosses the river; the limestone can be seen in large blocks, practically *in situ*, on the west bank, but in completeness the exposures compare very unfavourably with those previously noticed west of Cot Castle.

In addition to the river sections above described, there remains for consideration certain unique sections in the Hole Burn, in which strata are seen which lie well within the Calciferous Sandstone Series, lower than those at Cot Castle, and which we believe do not outcrop anywhere else in South Lanarkshire, since they are cut out by overlap.

The Hole Burn rises in the lavas north of Strathaven, and, flowing in a south-easterly direction, falls into the river Avon immediately above Glassford Bridge. In the latter part of its course, down to the Avon, only boulder clay can be seen, but from Muirburn House westwards there are excellent rock sections, the strata dipping in a general easterly direction. The highest beds exposed, at Muirburn House, are greenish sandy marls with balls of irony cement and sandstone bands; they resemble, and are probably equivalent to, the lowest strata of the Cot Castle cliff section, a conjecture supported by mapping and by the results of a diamond bore some miles to the north. Further upstream the sequence continues, descending through sandstones, with *Lingula* shales and a thin coal seam which has been wrought out at the crop. A sharp bend in the stream brings us to a low bluff of flaggy sandstone resting on a 3-foot bed of "shaly blaes." As an oil producer this seam is certainly of very low grade, but still it does contain a certain amount

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of shaly matter, as is evidenced by its relatively tough character, and resistance to weathering influences. It is the representative of the *Fraser Shale* of Cobbinshaw, the highest oil shale now worked in the Lothian shale fields. Rising gently towards the west, the shale runs along the crest of a low cliff of highly fossiliferous blaes with ribs and balls of ironstone and cement limestone, seen on the south side of the stream. The section is terminated by a 5-inch band of shaly blaes rising up from the bed of the stream, but is resumed on the north bank, where the shaly rib (accompanied by a dolerite sill) is again seen with 4 feet more of fossiliferous blaes underneath, resting on a hard band of burnt coal and dolerite. I have called the horizon the Netherfield Lime, as it can be traced southwards past the house of that name down to the Avon. The full section may be given as follows:—

Sandstone.

Fraser Shale—Shaly blaes with occasional ferns, &c.,		3 ft.
Crowds of small *brachiopods, lamellibranchs,* including occasional large examples of *Posidonomya becheri, gasteropods,* and *goniatites,*	Blaes with a 3-inch rib of clayband ironstone at the top,	6 ft.
	Hard cement limestone; occasional *Productus,* &c.,	5 ins.
	Blaes with balls of cement limestone.	4 ft.
Shaly blaes,		5 ins.
Blaes with abundant small *brachiopods, lamellibranchs, gasteropods,* &c., and strings of encrinital limestone at the base,		4 ft.
Burnt *Coal.*		

The lower half of the fossiliferous blaes, that is, the part under the 5-inch shaly rib, is crammed with small fossils, but they are not so well preserved as in the upper bed, and an efflorescence of gypsum covers the weathered fragments. The best collection can undoubtedly be made in the upper part of the section above the shaly rib. The finest fossils are, of course, to be found in the hard ribs and balls of limestone and ironstone, but with due care plenty of good specimens can be got from the blaes also. The material is ample and easily worked; the locality is quite the best for fossils that I have ever noticed in the Scottish Carboniferous rocks, and its interest is greatly

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enhanced by the low stratigraphical horizon of the bed. It may be added that a similar marine position has been got immediately beneath the Fraser Shale at Cobbinshaw and West Calder. (See list of fossils appended hereto.)

The coal under the Netherfield Lime is quite well seen a few yards upstream, where the seam is covered by a 3-foot dolerite sill, under which trial mines have been driven. Most of the coal is, however, badly charred, although some of it is relatively unaffected and will flame in the fire; it is also split up by dirt and fireclay partings, and altogether is quite unworkable at this point. Further south it was extensively worked about a hundred years ago along the outcrop on each side of the stream south of Floors, and the seam may be in good condition under the basin of the Limestone Measures between Waulkmill and Cot Castle; in that case at least a square mile of coal could still be wrought, the maximum depth being only 65 fathoms, with the 2 feet ("Wilsontown Smithy") coal and the Cot Castle Blackband at still shallower depths.

Proceeding with the Hole Burn section, the descending sequence continues west of the Netherfield Coal outcrop. About 16 feet below the coal and immediately under a band of flaggy sandstone an 18-inch seam of oil shale, with partings of irony cement, can be seen at the top of a high bank on the south side of the stream below the farm steading. This oil shale is of good quality, of the true Lothian type, and it represents the *Raeburn Shale*. Immediately beneath it is a 6-foot bed of blaes resting on sandstone, and containing small *Productus*, *Lingula*, &c., at the top; this is the equivalent of the shell bed found under the Raeburn in the Lothian fields ("Mungle Shell Bed" of the Oil Shale Memoir); in the lower parts of the blaes are ferns (especially *Telangium affine*) in excellent preservation.

Crossing to the north bank an irregular seam of dirty coal is seen in blaes under the sandstone, and still further upstream a massive freestone has been quarried at the West Quarter road bridge; on this sandstone are irregular nodules of limy cement, with rootlets, occasional entomostraca, and *Spirorbis*. The rest of the stream section is somewhat obscure. Rather more than a quarter of a mile above the bridge there are several exposures of variegated marl, of the type so commonly found

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in the West of Scotland fringing the Calciferous lavas, and evidently washed off a deeply-rooted surface of the volcanic rocks. These marls certainly lie a considerable distance below the Raeburn Shale seen downstream, and quite probably represent the Houston Marls of the Lothians; this correlation is supported by the fact that a coal seam, apparently lying beneath the marls, and therefore perhaps representative of the Houston Coal, has been worked in shallow pits along the outcrop at Laigh Walkerdyke Farm. The coal seems to be in two beds separated by flaggy sandstones and fakes. Both coals have been wrought, the lower being still visible, at least 12 inches thick, in the stream bed immediately below the road north of the farm steading.

The above-mentioned coals are the lowest sediments seen in the district. General considerations lead one to suppose that they lie close above the lavas, and that there is little or no faulting at the junction hereabouts, the rest of the Oil Shale division of the Calciferous being cut out by overlap.

At Strathaven itself the junction is, however, certainly faulted, for the Netherfield Lime comes close up to the lavas, and can be seen repeated by a fault in the Floors Burn, a quarter of a mile below the castle.

In conclusion, some general remarks on the appearance of the Oil Shale Group near Strathaven may be given.

The recent work of the Geological Survey strongly suggests that the Calciferous lavas of the Clyde plateau, fringing the coal and limestone basins of the Glasgow district, North Ayrshire, and South West Lanarkshire, are of much the same age as the Arthur Seat volcanics of Midlothian. There was therefore a prolonged interval between their emission and the deposition of the Hurlet Limestone—an interval during which the whole of the Oil Shale group of the Lothians was accumulated. But the Clyde lavas are immensely thicker than those of Arthur Seat; they stood out along with the Old Red Sandstone as great land masses during most of the Oil Shale period, and it was not until the Hurlet Limestone was deposited that they were finally buried beneath the Carboniferous sea. It therefore happens that in large areas of the West of Scotland the presence of great land masses of lava and Old Red Sandstone

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prevented the deposition of any sediments in Oil Shale time; and so along the south side of the Lanarkshire Coalfield we find a pronounced overlap of the Lower Limestone group on to the lavas and older rocks, the Oil Shale group being either quite absent or only represented by patchy occurrences of its uppermost portion. But near Strathaven and to the north the land was low and quickly submerged; the characteristic sediments of the Oil Shale group were therefore able to accumulate. And so here we find them at the present day reappearing from under the Lower Limestone covering, and nearly 20 miles to the south-west of the nearest Lothian shale field that of Cobbinshaw and Tarbrax. Between Stonehouse and Carnwath the Oil Shale Measures never outcrop; the unconformity at the base of the Lower Limestone group cuts them all out; but we know that the unconformity decreases rapidly to the north, and it seems more than likely that, running in a straight line between Strathaven and West Calder, there is a continuous development of the Upper Oil Shale group, beneath the covering of Coal Measures and Lower Limestones. Whether this concealed shale field will ever be worth proving is a doubtful matter; probably the Fraser and Raeburn Shales will be the only seams at a workable depth; but it is possible that the associated coals (such as the Netherfield and Wilsontown Smithy Coals) might be worth consideration at some remote date, when coal is a more valuable article than it is at the present time.

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LIST OF FOSSILS FROM THE BASKET SHELL-BED AT COT CASTLE.

The plants (all determined by Dr. R. Kidston) and most of the lamellibranchs (partly determined by Dr. Wheelton Hind) come from the upper part of the bed; Dr. G. W. Lee named the remaining fossils.—All from the Collection of the Geological Survey.

Archæopteris dawsoni (Stur.).
,, *tschermaki* (Stur.).
Lepidodendron sp.
Rhacopteris lindsæformis (Bunb.).
Sphenopteris cf. *gersdorfi* (Göpp.).
,, *sp. nov.*
,, *sp.*
Sphenopteridium sp.
Telangium affine (L. and H.).
,, *bifidum* (L. and H.).
Archæocidaris sp.
Lingula mytiloides (J. Sow.).
Martinia sp. nov.
Orbiculoidea nitida (Phill.).
Productus longispinus (J. Sow.).
,, *productus* (Mart.).
,, *pugilis* (Phill.).
,, *scoticus* (J. Sow.).
,, *undatus* Defranci } immediately above the
,, *sp. nov.* } Black-band Ironstone.
Rhynchonellid.
Schizophoria resupinata (Mart.).
Cf. *Composita ambigua* (J. Sow.).
Actinopteria persulcata (M'Coy).
Aviculopecten planoclathratus (M'Coy).
? ,, *clathratus* (M'Coy).
Amusium sp.
Cypricardella rectangularis (M'Coy).
Edmondia unioniformis (Phill.).
,, (two species).
Nucula gibbosa (Flem.).
Nuculana attenuata (Flem.).
Posidonomya becheri (Bronn.).
Protoschizodus axiniformis (Portl.).
Sanguinolites abdenensis (R. Eth.).
,, *angustatus* (Phill.).
,, *variabilis* (M'Coy).
Euphemus sp.
Macrocheilina obtusa (de Kon.).
Naticopsis sp.
Trepospira sp. nov.
Orthoceras cylindraceum—(Flem.).
,, *sulcatum* (Flem.).
Vestinautilus ? sp.
Goniatites ? [*Dimorphoceras gilbertsoni* (Phill.)].

Note.—Although the plants are not quite so numerous, the above list compares well with that from the same horizon in Calderwood Glen, East Kilbride, where it was first discovered some years ago.—[See "Summary of Progress for 1910," pp. 65-67 (*Mem. Geol. Surv.*)] At Cot Castle the most noticeable absentee is *Pterinopecten papyraceus.*

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LIST OF FOSSILS FROM THE NETHERFIELD LIME, IN THE HOLE BURN, ABOUT ¼-MILE WEST OF MUIRBURN.

Archæocidaris urei (Flem.).
**Amboccelia urei* (Flem.).
**Composita ambigua* (J. Sow.).
Lingula mytiloides (J. Sow.).
,, *squamiformis* (Phill.).
Orbiculoidea nitida (Phill.).
Productus longispinus (J. Sow.).
* ,, *martini*? (Sow.).
* ,, *concinnus* (Sow.).
,, cf. *corrugatus* (M'Coy).
**Actinopteria persulcata* (M'Coy).
Aviculopecten clathratus (M'Coy).
Cypricardella rectangularis (M'Coy).
Grammatodon? *sp.*
Nucula gibbosa (Flem.).
**Nuculana attenuata* (Flem.).
Protoschizodus axiniformis (Portl.).
Sanguinolites costellatus (M'Coy).
,, *omalianus* (de Kon.).
,, *variabilis* (M'Coy).
Bucanopsis sp. nov. [cf. *B marcouana* (Gein.)].
Euphemus urei (Flem.).
Ptychomphalina sp.
**Tropidocyclus sp.*
Glyphioceras micronotum (Phill.).
,, *truncatum* (Phill.).
Cœlonautilus sp.
**Stroboceras sulcatum* (J. de C. Sow.).
Vestinautilus sp.

* These were not obtained by the Survey, but belong to Mr. James L. Begg, who also has most of the other species in his excellent collection from this locality.

Note.—To the above list may perhaps be added *Posidonomya becheri*, of which I obtained a large and typical example about the middle of the bed; being very fragile, however, it broke up during transit to Edinburgh and never reached Dr. Wheelton Hind.

In connection with this list one should also note that the locality of "Gallowhill, near Strathaven," known to the older members of the Society, must surely refer to the outcrop of the Netherfield Lime and Coal, formerly worked opencast south of Floors (p. 12).—R.G.C.

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The River Cliff at Cot Castle. Upper Calciferous Strata.

R. G. Carruthers, Photo.

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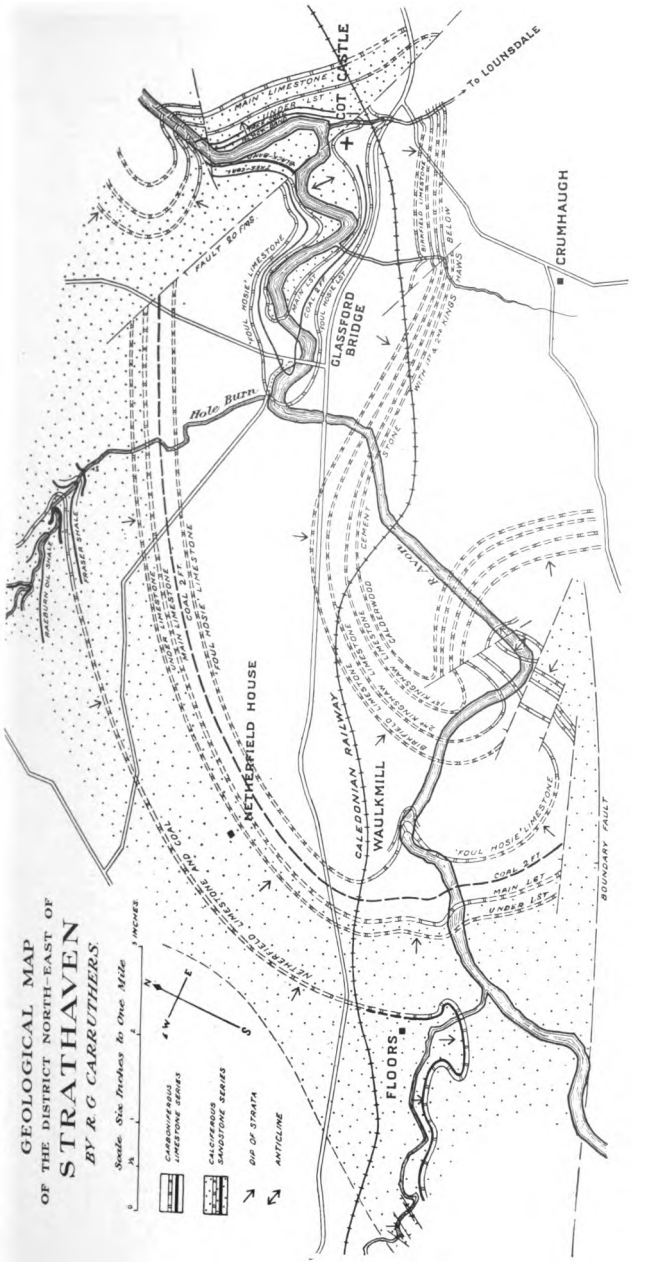

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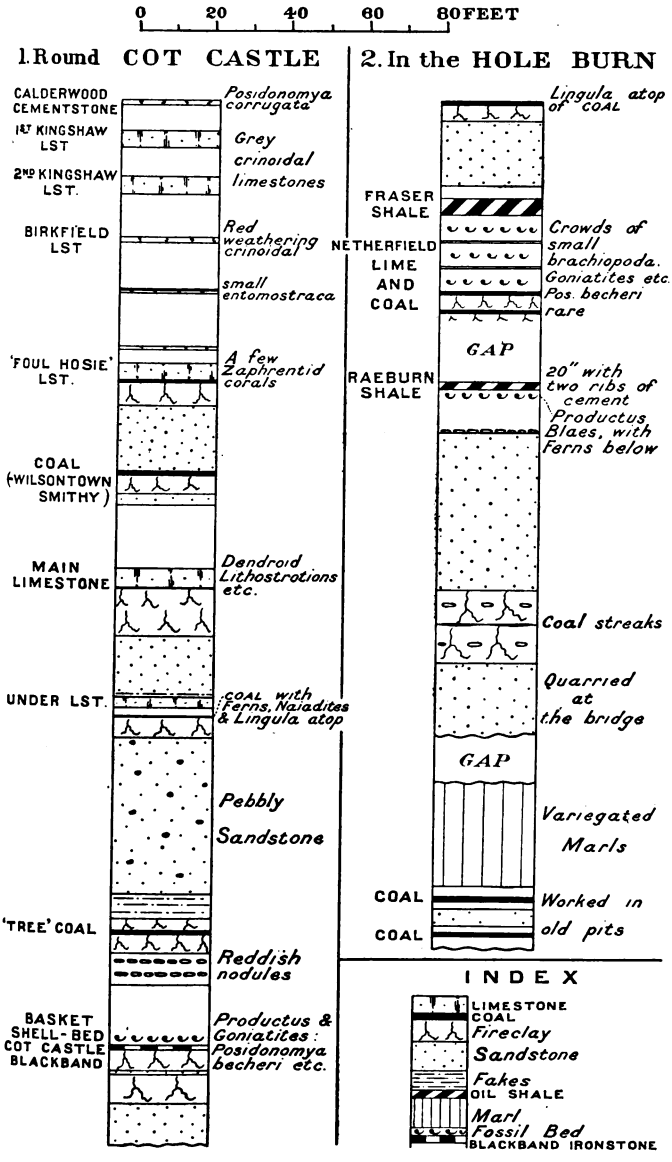
VERTICAL SECTIONS near STRATHAVEN



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No. XIII.—Notes on the Discovery of Fossil Chitons in Fife; with Photographs and Drawings of all the Fossils found in the Section. By R. Dunlop.

[Read 9th April, 1914.]

The section to which I am about to call your attention is situated about one mile south-east of Dunfermline Lower Railway Station on the Lyne Burn, and on the bend of the burn below Woodmill Bleachfield.

The strata containing the fossils rest on the Hurlet Limestone, which crops out about a quarter of a mile down the burn from the fossil bed (see Plate XIX., Fig. 1), and from the condition of the refuse heaps round this crop-out it must have been a very long time since the limestone was worked, as large beech and other trees growing on the refuse heaps have matured, and are just now being cut down. The working of this quarry would seem to have been too early for any note of its fossil records to have been preserved. In the Memoirs of the Geological Survey on "The Geology of Central and Western Fife and Kinross," by Sir Archibald Geikie, F.R.S., D.C.L., D.Sc., 1900, eight species are recorded from a section three-quarters of a mile further up the burn than the present sections on the right side of the burn below Touch Bleachfield, which is now too much screed for examination without much labour. The following are the eight species recorded:—*Productus longispinus*, *Rhynchonella pleurodon*, *Streptorhynchus crenistria*, *Sanguinolites tricostatus*, *Macrochilina sp.*, *Narica variata*, *Bellerophon decussatus*, *Orthoceras sp.*

In the present section *Productus longispinus* is fairly common, but not very well preserved, being often crushed. *Rhynchonella pleurodon* is not so common; I have only got four specimens. Regarding *Streptorhynchus*, I have seen what I thought might be this species, but the specimen was not good enough to put on the list. All the others are common, with the exception of *Narica variata* (unless a small *Naticopsis* turns out to be this species).

A bore was put down in 1905, about 50 to 80 yards further up the burn from the section, by J. C. H. Reid, Esq., of Woodmill Bleachfield. They went down 36 fathoms, and came on a

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limestone at that depth, which possibly may be one of the Abdens in this bore. No coal was recorded below the Hurlet Limestone, but at Elgin Bleachfield, south of the town, a bore was put down in 1892 also for water (recorded in Geikie's "West Fife," page 49), which, although on lower ground, showed a fault of at least 120 feet. Below the Hurlet in this bore 2 feet of coal is recorded, and at the same distance as the Woodmill bore they also came on a limestone.

The higher strata represented in Pittencrieff Glen (further west than Elgin Bleachfield) shows that the fault must run more from east to west than north to south.

Fifty years ago—10th November, 1864—a provisional notice of a new Chiton and a new species of Chitonellus from the Carboniferous Rocks of Western Scotland, by Mr. John Young, with description by Mr. James W. Kirkby, and a plate, was read to this Society, and published in its *Transactions*, describing *Chiton humilis* and *Chitonellus youngianus*. Nothing else on Chitons appears in the *Transactions* of this Society up to the present day, but in the *Transactions of the Natural History Society*, 1898, page 322, there is a paper by John Young on "Chitonellus, Recent and Fossil," and in the *Geological Magazine*, 1869, page 340, J. W. Kirkby and Young, "Notes on Some Remains of Chitons and Chitonellus from the Carboniferous Strata of Yorkshire and the West of Scotland," and a more up-to-date paper appears in the *Transactions of the Natural History Society*, 1881, by Mr. R. Etheridge, jun., F.R.Ph.S.Ed., describing ten species, and referring to other four, for some of which he uses the word "doubtful." All of these records, however, are from the West of Scotland, and, so far as I can find, none has been recorded from the east or from Fife.

In the west the specimens found were comparatively small. In the east they are much larger, and I collected upwards of eighty specimens in 4 square feet. *Chiton gemmatus*, which was only represented in the west by a very poor specimen, found by the late James Thomson, F.G.S., at Gallowhill, near Strathaven, and was lost in the fire at Kilmarnock, is found here large and in good preservation, and is the most plentiful. Plate XXII., Fig. 4, shows a specimen which I sent to Dr.

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Wheelton Hind, B.Sc., F.G.S., who compared it with de Koninck's figures. It would appear from Mr. R. Etheridge's description of Mr. James Thomson's specimen that it was doubtful. It is as follows:—(*Natural History Society of Glasgow's Transactions*, vol. v., page 91)—"The surface ornament is arranged like that of *Chiton gemmatus*, and at first sight the outline is similar. On a closer comparison, however, it is evident that the lateral margins in the Scotch form are more evenly rounded and without any obliquity. Moreover, in the latter there existed a central obtuse keel more apparent towards the front or anterior margin. There is also an entire absence of the faint tripartite division of the surface visible in de Koninck's species. Finally, the apophyses are much narrower and longer, and project more from the front in the Strathaven specimen, whilst the anterior margin is a little more concave."

From the above description it looks very doubtful if this were the species referred to.

Plate XXII., Figs. 2 and 3, compare very well with Etheridge's Fig. of *Armstrongianus*, and Fig. 6, *Cordatus* of Kirkby. I can find nothing figured to compare with Fig. 5; the specimen has a cornice round it that none of the others has, and I name it provisionally *Chiton Woodmillensis*.

The fact that a modern Chiton has eight plates, all differing in structure in some respects, points to the great difficulty there is in naming single plates. The specimen shown in Plate XXI., Figs. 6A and 6B, was at first thought by Dr. Wheelton Hind, B.Sc., F.G.S., to be a new shell. I sent him all the specimens, and on a closer examination he came to the conclusion that it was the young of *Nucula brevirostris* (Fig. 6). Plate XXV., Fig. 1, shows what I thought to be a large Nautilus; a photo of it was sent to Dr. Wheelton Hind, B.Sc., F.G.S., who regards it as a large Euomphalus. However, I have let it stand Nautilus (?) at present, and by and by I will send the specimen itself to him for closer examination.

When the writer was in New Zealand he got a slab from the Mesozoic formation with a large number of Turritella, with their larger ends all lying one way, which he thought was due to tidal action. This was found to be the case, as he

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noticed the same thing taking place on the shore at the present day. At Woodmill, in a zone near the bottom of the section where the larger Orthoceras are mostly to be got, of the ten specimens found, their heads were all lying to the east, although I found several about the same position (smaller ones) lying north and south; still, it points to their position being due to currents, and shows the importance of paying attention to the position of fossils when found. If geologists would note this, we might in time find evidence to warrant our saying how the tide flowed in Carboniferous times.

I am very much indebted to Dr. Wheelton Hind, B.Sc., F.G.S., and Dr. F. A. Bather, of the British Museum, for naming many of the fossils, and for other kind assistance, and to J. C. H. Reid, Esq., of Woodmill Bleachfield, for allowing me to publish the journal of the bore put down at the works, and to the Carnegie Dunfermline Trustees for defraying the expense of the plates.

JOURNAL OF BORE PUT DOWN AT WOODMILL BLEACHFIELD.

Commenced 13th October, 1905, finished 19th December, 1905.

	Fathoms.	Feet.	Inches.
Depth of well,	5	0	6
Blaes and balls,	5	0	6
Limestone, hard,	1	2	0
Fakey fireclay,	1	0	8
Sandstone, hard,	0	2	0
,, softer,	1	5	4
Fakes and blaes,	3	2	10
Dark fakes,	0	2	6
Sandstone, fakey,	0	3	6
,, firm,	2	3	2
Fakes,	0	5	0
Sandstone, hard,	4	0	9
Fakes,	0	0	10
Sandstone, extra hard,	0	0	10
Fakes and blaes,	1	2	10
Coal,	0	0	10
Fakes,	0	1	8
Sandstone, firm,	2	1	9
Fakes and blaes,	1	0	0
Coal,	0	1	2
Sandstone, extra hard,	1	1	0
,, softer,	1	0	0
Fakes and sandstone,	0	2	0
Blaes,	1	0	9
Limestone, hard,	0	1	7
Depth,	36	2	0

(Signed) THOMSON BROTHERS, LTD., Dunfermline.

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PLATE XIX.

1. Showing where the Limestone crosses the Lyne Burn. The waterfall is over the Limestone.
2. Section in which the fossils were got.

PLATE XX.

Echinodermata.

1. *Archæocidaris urei* (Flem.).

Crustacea.

2. *Griffithides mesotuberculatus* (M'Coy).

Brachiopoda.

3. *Chonetes laguessiana* (de Koninck).
4. ,, ,, ,,
5. *Discina nitida* (Phill.).
6. *Productus longispinus* (Sow.).
7. ,, *scabriculus* (Martin).
8. ,, *semireticulatus* (Martin).
9. *Rhynchonella pleurodon* (Phill.).
10. *Spirifera duplicicosta* (Phill.).

Lamellibranchiata.

11. *Leiopteria lunulata* (Phill.).
12. *Pseudamusium anisotum* (Hind).
13. *Posidonomya corrugata* (R. Ether.).
14. ,, *Becheri* (Brown).
15. *Aviculopecten clathratus* (M'Coy).
16. *Pinna mutica* (M'Coy).
17. *Nuculana* (*Leda*) *attenuata* (Flem.).
18. ,, ,, ,, ,,
19. ,, ,, ,, ,,
20. *Nucula Scotica* (Hind).
21. ,, ,, ,,
22. ,, *æqualis* (Sow.).

PLATE XXI.

Lamellibranchiata—*continued.*

1. *Nucula gibbosa* (Flem.).
2. ,, ,, ,,
3. ,, ,, ,,
4. ,, *luciniformis* (Phill.).
5. ,, ,, ,,
6. ,, *brevirostris* ,,
7. ,, ,, ,,
8. ,, *oblonga* ,,

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PLATE XXI.—*continued.*

9. *Ctenodonta levirostrum* (Portlock).
10. ,, ,, ,,
11. *Cypricardella rectangularis* (M'Coy).
12. ,, *selysiana* (de Kon.).
13. *Edmondia unioniformis* (Phill.).
15. *Grammatodon geintzi* (de Kon.).
16. *Sanguinolites* (*Leptodomus*) *costellatus* (M'Coy).
14. ,, *tricostatus* (Hind).
17. *Solenomya primæva* (Phill.).
6A. Young of Number 6, magnified 5 diam.
6B. ,, ,, ,, ,,

PLATE XXII.

GASTEROPODA.

1. Showing a slab of the Chiton bed reduced 1 diam.
2. Chiton *Armstrongianus* (Eth.).
3. ,, ,, ,,
4. ,, *gemmatus* (De Kon.).
5. ,, *Woodmillensis*, N.S.
6. ,, *cordatus* (Kirkby).

PLATE XXIII.

1. *Dentalium* (*Entalis*) *priscum* (Goldffuss).
2. ,, *Dalryense* (Young), mag. 5 diam.
3. ,, ,, ,, ,,
4. *Euomphalus carbonarius* (Sow.).
5. ,, ,, ,,
6. ,, sp. magnified 6 diam.
7. *Loxonema brevis* (M'Coy), magnified 5 diam.
8. ,, ,, ,,
9. ,, *curvilinea* (Phill.), magnified 5 diam.
10. ,, ,,
13. ,, sp., showing decussat structure, magnified 5 diam.
11. *Murchisonia striatula* (De Kon.), magnified 5 diam.
12. ,, ,, ,, ,, ,,
14. *Capulus*, sp., magnified 3 diam.
15. *Macrocheilus* (*Macrochilina*) *acutus* (Sow.).
16. *Pleurotomaria conica* (Phill.).
17. ,, sp.
18. *Bellerophon urei* (Flem.).
19. ,, ,, ,,
20. ,, *decussatus* (Flem.).
21. ,, ,, ,,
22. ,, *oldhami* (Portl.).
23. ,, *decussatus var striatus* (Flem.).
24. ,, ,, ,, ,,
25. *Mourlonia Portlockiana* (de Kon.).
26. ,, ,, ,,
27. *Naticopsis*, sp. magnified 5 diam.
28. ,, ,, ,,

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1. Where the Limestone crosses the Lyne Burn.

2. Section in which the fossils were got.

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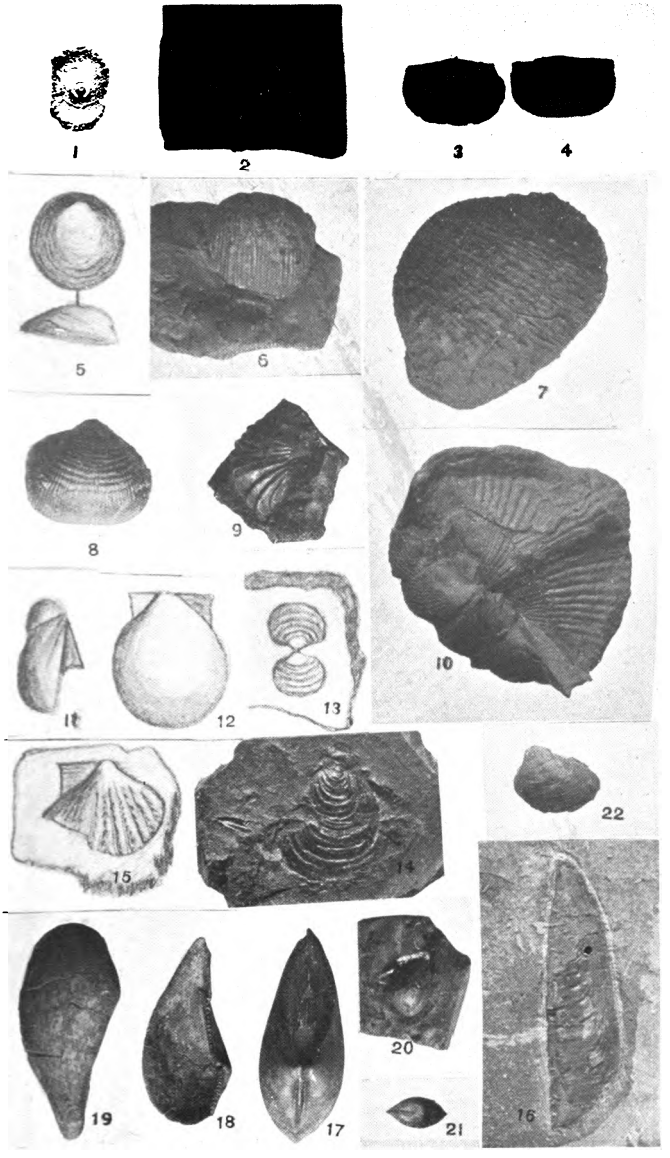

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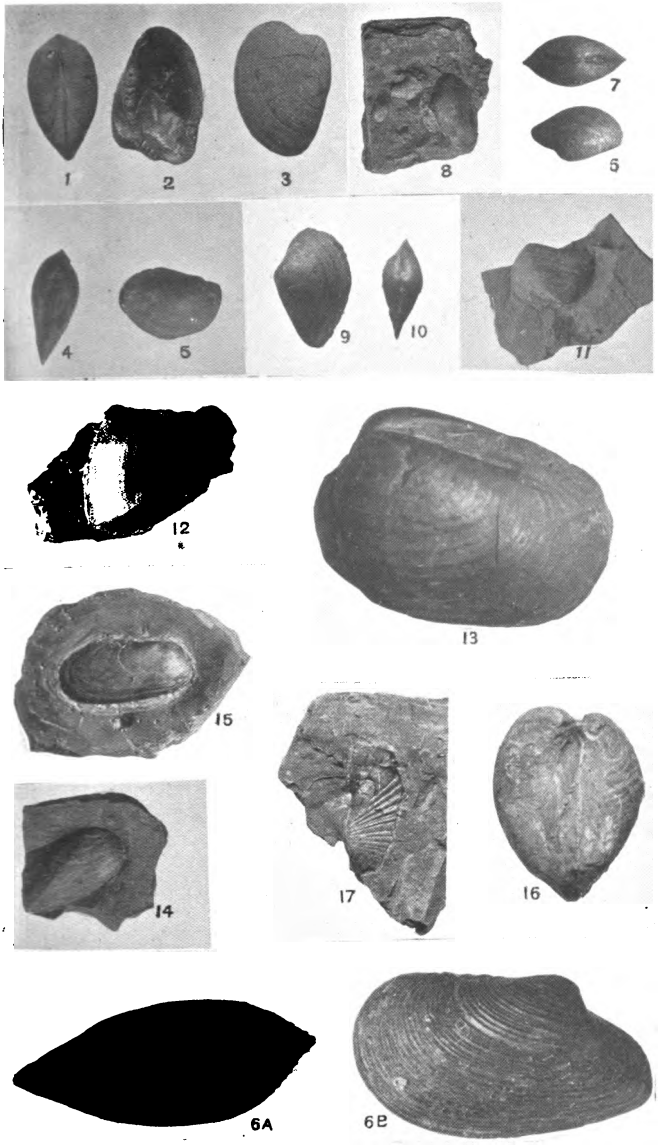

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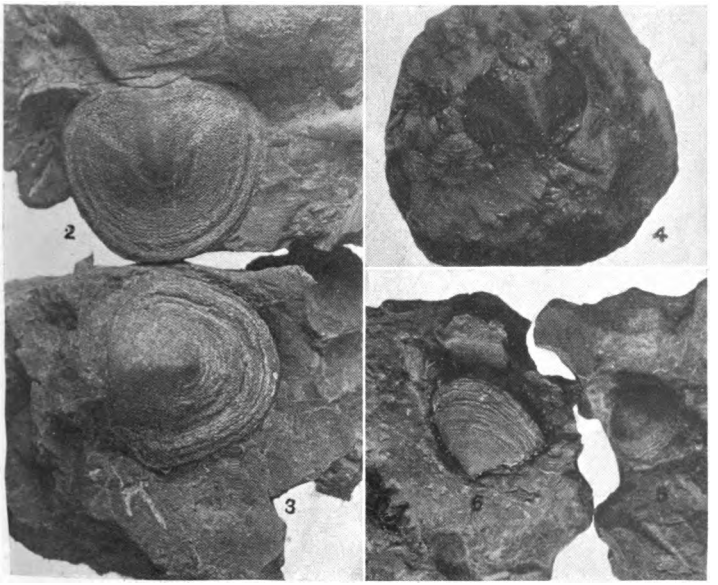
1. Chiton bed reduced 1 diam.



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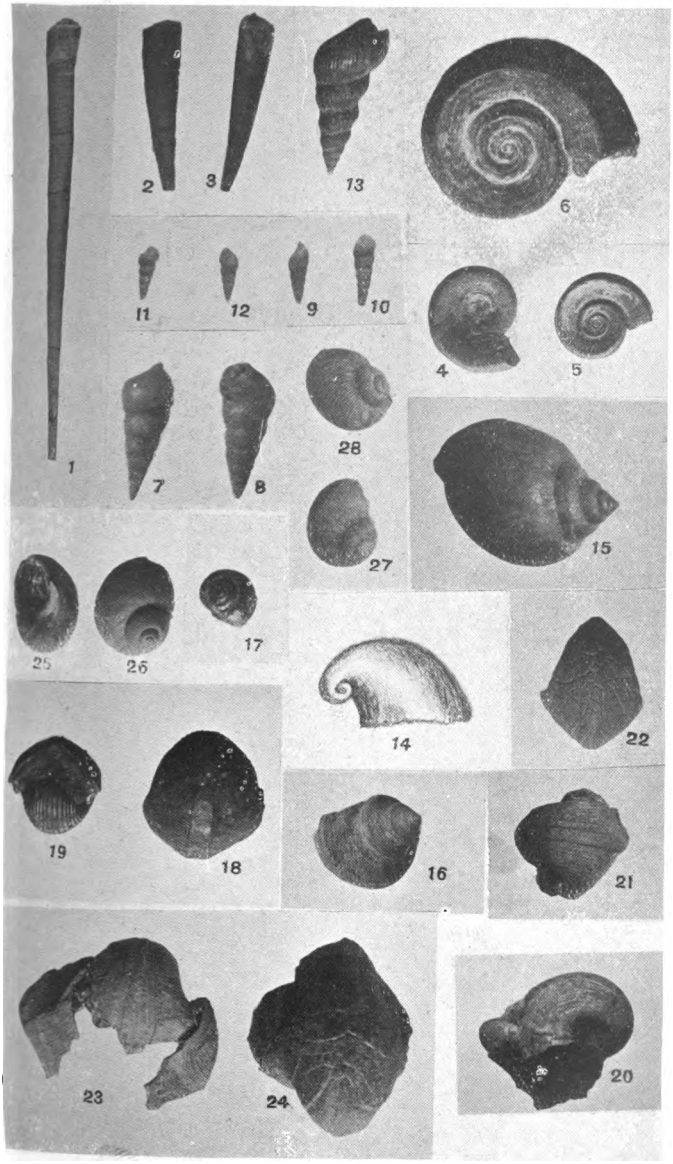

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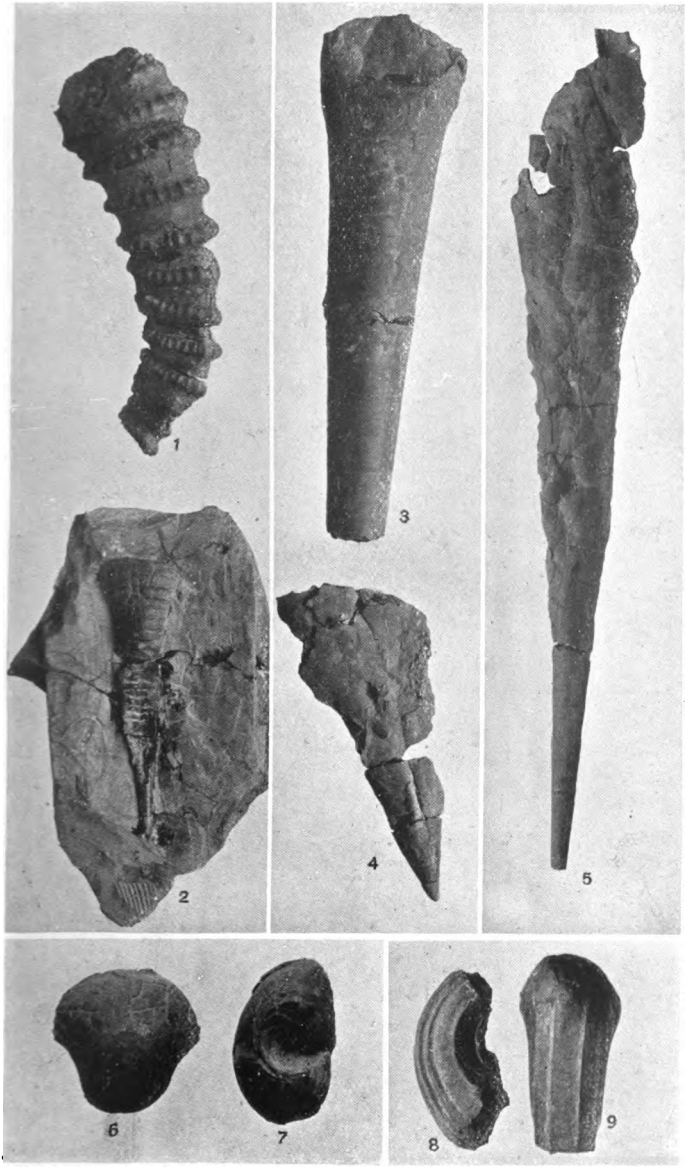

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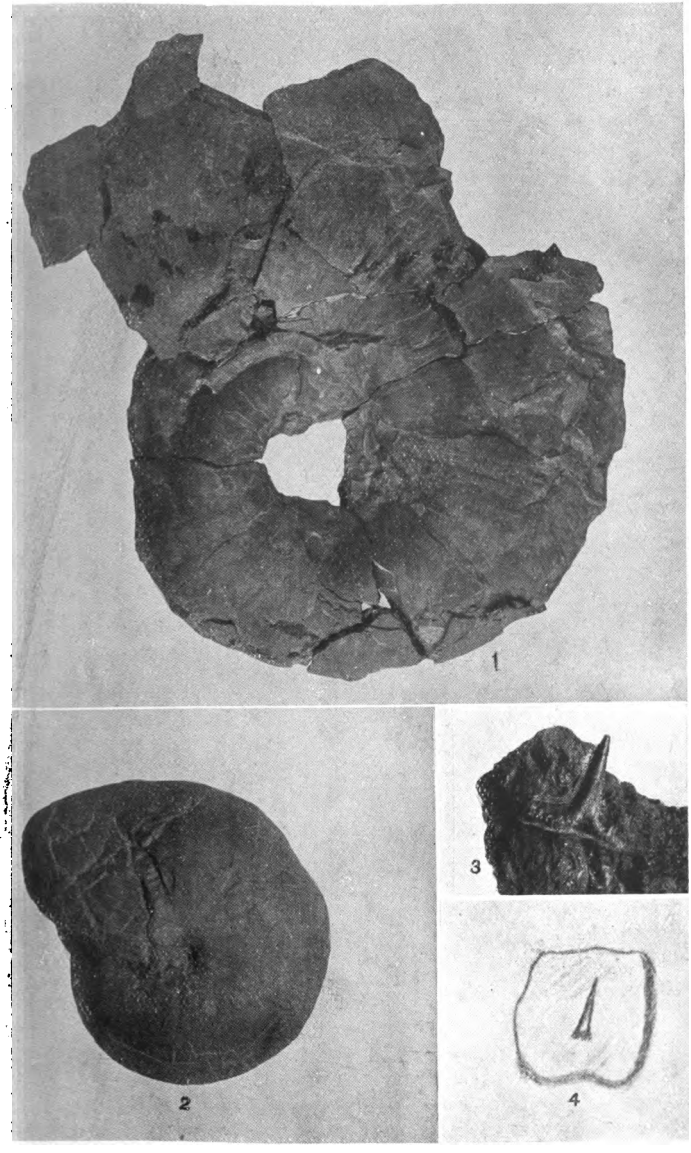

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PLATE XXIV.

Cephalopoda.

1. *Cyrtoceras rugosum* (Flem.), reduced $\frac{1}{3}$.
2. *Orthoceras sulcatum* (Flem.), reduced $\frac{1}{3}$.
3. ,, *cylindraceum* (Flem.), reduced $\frac{1}{3}$.
4. *Cyrtoceras unguis* (Phill.), reduced $\frac{1}{3}$.
5. *Orthoceras læve* (Flem.), reduced $\frac{1}{5}$.
6. *Coloceras listriale* (Sow.), reduced $\frac{1}{3}$.
7. ,, ,, ,, ,,
8. *Nautilus sulcatus* (Flem.), reduced $\frac{1}{3}$.
9. ,, ,, ,, ,,

PLATE XXV.

1. *Nautilus*, sp., reduced $\frac{1}{2}$.
2. *Glyphioceras* (*goniatites*) *obtusum*.

Fish Teeth.

3. *Cladodus*, sp.
4. Small fish tooth.

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No. XIV.—The Permian and Triassic Rocks of Arran. By Professor J. W. Gregory, D.Sc., F.R.S.

[Read 14th May, 1914.]

1. The Ages assigned to the Upper Red Rocks of Arran.

2. The Upper Division—

   (1) Sections around Levencorroch.
   (2) Section near Bennan Head.
   (3) Section north of Lagg.
   (4) Sections near Ballymichael.
   (5) Relations of the previous Sections.

3. The Lower Division.

4. The Classification of the Upper Red Rocks.

The dates in thicker figures refer to the List of References at the end.

1. The Ages Assigned to the Upper Red Rocks of Arran.

Most of the southern part of Arran consists of a series of red rocks which have been assigned at various times to each of the geological Systems, from the Devonian to the Trias. Sedgwick and Murchison, in 1829, referred them (**1829**, pp. 32, 33, and section, pl. 3) to the New Red Sandstone. Sir Andrew Ramsay, in **1841** (p. 77), adopted the same conclusion for most of the formation, though he referred (*e.g.*, section 2, opp. p. viii.) a considerable part to the Carboniferous. Bryce, in **1859** (p. 70), transferred the whole group to the Carboniferous, as he held that they were interstratified with Carboniferous Limestones, and he expressed himself confident that "the distinguished geologists" who had referred these beds to the New Red Sandstone "will be the first to agree to this view." In the fourth edition of his Geology of Arran (**1872**, p. 15) he provisionally identified them with the Calciferous Sandstones, and therefore placed them at the base of the Carboniferous. This view was shown to be impossible for the Red Sandstones at

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the Cock of Arran when, in 1874, Wünsch and Thomson (**1877**) found fossiliferous Carboniferous pebbles in them, and referred the beds to the Lower Permian. They are shown as Carboniferous by Goodchild in the map accompanying H. B. Woodward's Geology of England and Wales (**1887**, 2nd edition). Subsequently Sir Archibald Geikie (**1892** and **1893**, p. 801) referred these red rocks to the Upper Old Red Sandstones, but afterwards led the way in their transference to the horizon to which they in all probability belong; for, owing to the resemblance of the Brodick Sandstones to those on the mainland, he remarked (**1897**, vol. ii., pp. 58, 418, 419) that "good reasons have been given for classing as Permian the bright red sandstone" of central and southern Arran. This view was supported in 1898 by Gunn, who (**1898**, p. 273) provisionally accepted the beds as Permian; and he elsewhere remarked (**1898**, No. **2**, p. 124) that this view is extremely probable, owing to their close resemblance to the Permian beds of Ayrshire. They were thus represented on the first edition of the Geological Survey Map of South Arran (Sheet 13, issued 1898; on the second edition, 1902, the age was altered to Trias). Two years later, however, the discovery of the Rhætic fossils amongst the volcanic agglomerates of Ard Bheinn, in central Arran, led to a new change in the age allotted to this Red Sandstone Series.

The Rhætic beds are closely associated with some red marls which Gunn referred to the Keuper. In this identification he was doubtless correct; but he unfortunately went further, and concluded that the Red Sandstone Series is "probably all of Triassic age" (Gunn, **1900**, p. 134); and in the following year C. B. Wedd remarked (**1901**, p. 112) that the discovery of Rhætic fossils "affords the strongest proof that the newer red sandstones of the southern half of the island are really Triassic." In the Survey Memoir on North Arran (**1903**, p. 67), Gunn claimed that the discovery of the Rhætic bed "fixes pretty definitely the Triassic age of the upper division of the formation"; but both in his memoir and the map the whole series is referred to the Trias. That view was not only adopted for Arran, but the whole of the post-Carboniferous Red Sandstones on the mainland of south-western Scotland have been

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transferred on the later Geological Survey maps (Geological Survey, 1904) to the Trias. Sir Archibald Geikie did not adopt this course for the mainland in the new edition of his map of Scotland; but he accepted the Triassic age of the whole of the Upper Red Sandstone Series of Arran. Mr. Jukes-Browne (**1911**, p. 208) has pointed out that, while the upper beds are Trias, the lower sandstones are probably Permian; and this conclusion seems to me correct.

The Geological Survey has not published any memoir on southern Arran, and the upper rocks only occur to a slight extent in northern Arran. The information published on them is not very full, hence interest in desert formations led me to undertake a series of visits to the area to see what evidence the beds offer as to the physical conditions under which they were deposited.

Mr. Gunn classified the rocks as follows (**1903**, p. 67):—

Upper Trias—Keuper,	Red and mottled shales or marls with thin beds of white, yellow, or grey sandstone, and occasional thin bands of nodular limestone.
Lower Trias—	4. Light coloured and yellowish sandstones, sometimes red, with calcite in cavities. 3. Reddish sandstones with some conglomerates. 2. Conglomerates alternating with sandstones. 1. False-bedded red sandstone of Brodick and Corrie.

2. The Upper Division.

The Keuper occupies chiefly the southern and south-western part of the island, while the lower division occupies the north-eastern area, extending from Holy Island westward to Burican, and along the eastern coast from Brodick to the southern side of Whiting Bay.

1. *Sections near Levencorroch.*—The upper division, or Keuper, is best displayed in the cliff sections from Kildonan to beyond Bennan Head, and in the various stream sections going inland along that part of the coast. A representative section of the upper division can be seen by following the Levencorroch Burn, which flows between Auchenhew Hill and Levencorroch Hill, and along the next stream to the east, which passes to the

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east of Auchenhew Hill, and discharges to the sea beside the "Kildonan store." In the upper part of Levencorroch Burn the beds are almost horizontal. The sequence in descending order, from a point on the stream where the base of the basalt sheet that forms the top of the Auchenhew Hill at the level of about 620 feet, is as follows:—Immediately below the basalt are red- and chocolate-coloured shales, followed by alternate layers of red shale and white sandstones. Some of the red shales have been altered to green, either wholly or in veins and spots. The upper waterfall is at the level of about 570 feet, and below it are some light blue calcareous sandstones rich in white mica. Some of this rock is well bedded and some is false bedded, and the rock weathers into cavities. The rock, like most of the blue sandstones, effervesces freely with acid. Microscopic examination[1] shows that it is a fine-grained sandstone composed of sharply angular grains of quartz and felspar; flakes of white mica are scattered through it and crowded along some bedding planes. The surfaces of some of the sandstone layers are marked by a network of raised bands, due to the sand having been pressed into shrinkage cracks in the adjacent beds of clay. The red shales in this part of the section are accompanied by bands of red marl, which has the typical, irregular fracture of the English Keuper marl. Microscopic examination shows that they are full of minute rhombohedra, which, as the rock effervesces freely with cold acid, are calcite.

At the level of 525 feet are two layers of calcareous nodules or potato stones. Microscopic examination shows that these nodules consist mainly of an aggregate of very fine calcareous angular granules, and embedded in this groundmass are larger angular fragments of quartz and flakes of mica. These potato stones are clearly secondary calcareous segregations.

Thirty feet below these, at 495 feet, is another waterfall due to a basic sill, and below it occur further red marls and green shales. At 450 feet is a lenticular band of quartzite. Thirty feet below it, at the end of the main section, are thicker bands of bluish white sandstone, with some of the markings usually described as fucoidal; they are about a quarter of an inch wide,

[1] For preparation of the material and laboratory tests I am indebted to Mr. W. R. Smellie.

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and branch repeatedly. These bluish white sandstones contain many layers, which are white owing to the abundance of white mica. Some of the blue bands have been broken up into a breccia during the settlement of the rocks during consolidation.

The dip at the lower end of the section is about 7 degs. northward. Below this band a grass-covered slope extends to the road (260 feet), interrupted, however, by one clear exposure of red and green shales. South of the road a gully shows occasional exposures of red shales on the floor of the hanging valley above the waterfall at the mouth of Levencorroch Burn. Beneath this fall are red and green shales, which have been cut through to the underlying white calcareous sandstones and chocolate-brown sandstones; and these are succeeded, at the lowest exposure seen here, by more red and green shales.

The lowest beds of the Levencorroch section dip eastward below sea-level; but some of the overlying beds are better seen in the Auchenhew Burn, a little above the "Kildonan store." The section exposed on the road cutting north of the store is as follows:

Red shale with rare green spots,	6 feet and over.
Green shale,	6 inches.
Light brown to buff soft sandstone,	14 "
Bar of hard buff sandstone,	5 "
Green sandy shale,	4 "
Buff to white soft sandstone, with layers of green shale,	2 feet.
These green layers increase in proportion till they form a basal layer of green shale,	1 foot.
Red nodular shale, ending below in a line with green patches,	3 feet.
Red nodular shale,	5 "
Green shale,	8 inches.
Buff coarse sandstone,	2 "
Buff sandstone decomposed to sand,	3 "
Green shale,	6 "
Red shale,	6 "
Green shale,	3 "
White to buff sand with brown spots, one part is false bedded,	15 "
Green shale,	—
Bar of white to brown or buff sandstone,	4 "
Red nodular shale,	4 feet.
	27 feet 4 inches.

2. *Sections near Bennan Head.*—North of Bennan Head the

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Keuper beds include a layer of sandstone which is almost as compact as a quartzite; west of Bennan Head, on the cart road from the shore on to the top of the cliff of Torr nan Uain, is an excellent exposure which, in descending order, is as follows:—

Nodular red marl with curved irregular fractures,	3 inches.
Red shale,	10 "
Red nodular marl,	3 "
Red shale,	15 "
Potato stones,	2 "
Red shale,	14 "
Band with occasional large potato stones,	$2\frac{1}{2}$ "
Red shale,	3 "
Potato stones,	2 "
Red shale,	6 "

The lowest part of the section consists of red mudstones, shales, and marls, some of which have the aspect of typical Keuper marl.

The thickness of the Keuper series in this district must be over 700 feet, and Mr. Gunn's estimate of nearly 1000 feet for this division is probably correct. The Keuper marls and shales include no conglomerates except contemporary breccias due to the breaking up of some layers during the settlement of the rocks.

3. *Sections North of Lagg.*—As the beds at Torr nan Uain are in the centre of a synclinal, they probably show the highest part of the Keuper exposed in southern Arran; and the lowest beds in this series in the same district, according to the Survey map, should occur between High Clauchog (on the Allt Mor Cloined, which reaches the sea at Lagg), and the road along the Sliddery Water, 3 furlongs north of Bennecarrigan.

The boundary between the two divisions of the "Trias" is there indicated by a dotted line passing to the south of the tributary to the Sliddery Water from Cnoc Clauchog. The long junction of the upper and lower divisions to the west of the Sliddery Water is shown as faulted, and the boundary between Bennecarrigan and High Clauchog appeared from the map to offer the best prospect in Arran of observing the relations between the two divisions. Allt Mor Cloined, near its junction with the tributary from High Clauchog, shows the following section:—

4 or more bars of sandstone, from 2 inches to 6 inches thick, in red and green shales.

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3 feet red and shaly sandstone or mudstone; breaks to small irregular fragments.
6-inch bar of sandstone, bordered above and below by green shales.
8-10 feet of red shale with green spots, and red or chocolate argillaceous massive sandstone.

The sandstones are coarse-grained, and pass to soft grits; their grains, on microscopic examination, are very angular, and some are tabular. The constituents are mainly quartz, various felspars, white mica, and cleavage fragments of calcite. These rocks resemble those exposed below the lowest waterfall on the Levencorroch section.

The section on the tributary from High Clauchog begins with red shales, which contain layers of sandstone from 1 to 10 inches thick, and dip 15 degs. to the south. The sandstones are sometimes white, with green lines and spots; and some of the red shales are much jointed with flat surfaces instead of the curved fractures of the typical red marls. The burn rises more quickly than the beds, and exposes younger members of the series; a cliff on the right bank consists of massive sandstone, which is buff in colour, with green lines, and below this is the following section:—

Red shale,	5 feet.
Alternation of sandstones and red and green shales,	6 "
Bar of earthy limestone,	6 inches.
Red shale with some green horizontal streaks,	8 "
Clayey limestone,	4 inches to 1 foot.
Red shale,	2 feet.
Potato stones,	4 inches.
Red shale,	2½ feet.
Layer of larger potato stones,	5 inches.
Red shale passing down to red sandstone,	6 feet.

This part of the section agrees with the calcareous series of the upper Levencorroch Burn. The dip becomes steeper, and, continuing north-west, the burn exposes red shales and sandstones, and reaches the moor, where the beds, according to the Survey map, belong to the lower division. But the only rocks I could find *in situ* were shale and sandstone, which in aspect and weathering agree with the lower beds of the Upper Division, and not with the Lower Division. The stream from Cnoc Clauchog, in the part of its course where it flows to the west-north-west towards Sliddery Burn, shows a good exposure of the rocks. The eastern exposures are of yellow weathering sandstones, which dip south-west by west. The sandstone has some thin,

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false-bedded layers in which the false bedding dips westward. The series contains also layers of green and red shales, and they were probably all red originally.

At the next exposure the beds dip 15 degs. to the south-south-west, and consist of yellow weathered sandstones, separated, where the peaty moor waters cannot percolate, by red shales. The last sections upon this burn show shales and thin sandstones in which only patches of the shale are red. The whole of the series in this burn appears to me to consist of the Keuper beds decolorised by weathering, and I did not see any exposure of the lower rocks in these sections.

As I was unable to follow the Sliddery Water northward to find the southern border of the Lower Division, Mr. Tyrrell, who was subsequently mapping in this district, kindly examined the area, and concludes that the boundary between the two divisions should be drawn further north. His observations are recorded in a paper published in this volume, and show that, though the boundary is difficult to determine in this neighbourhood, here, as elsewhere in Arran, there is no evidence of an unconformity between the two divisions.

4. *Sections near Ballymichael.*—Representative exposures of the Keuper beds also occur in western Arran, near Blackwaterfoot and Ballymichael. At Blackwaterfoot there are a few exposures of these beds, one showing horizontal red shales and sandstones separated by a dyke from the same beds, which have been tilted until they are almost vertical. The sections along the burn south of Ballymichael Glen are interesting, as, according to the Survey map, they show the Upper and Lower Divisions in contact.

The sections along this burn are numerous, but the division between the two groups is indicated by a dotted line indicating an uncertain boundary. About 60 yards up the burn from the road is an exposure of red shale, with thin sandstones, which are broken and marked with green spots. Beyond the fence is a section showing an 8-inch bar of yellowish-green sandstones composed of sharp grains, and resting on red shales which are weathered to yellow; the beds here dip 20 degs. westward. A little further up the stream is a ripple-marked red sandstone

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which, though not actually *in situ*, was obviously derived from close by. About the 300 feet contour is an exposure at a small waterfall of red sandstone over red shale. At the level of about 315 feet is a basalt dyke.

On the Geological Survey map the boundary between the Keuper and the lower rocks is shown crossing the burn at the level of about 300 feet; but the carious sandstones at the top of the Permian beds appear on the moor to the east of the stone wall, and beyond a felsite dyke at the height of about 450 feet. I should therefore place the junction between the Upper and Lower Divisions further up the stream than the point adopted by Gunn, and should include the red shales and red sandstones between the contours of 300 and 400 feet in the Upper Division.

5. *Evidence of the Previous Sections.*—The preceding series of sections is sufficient to illustrate the general character of these Triassic beds. The exposures in the Levencorroch Burn and west of Bennan Head show the Upper Division, and those near Ballymichael and Allt Mor Cloined the lower part of the series. The general classification of the beds is given on the table, p. 186.

3. The Lower Division.

The beds of the Lower Division of these post-Carboniferous sandstones are better known, as they are well exposed in the shore sections at Brodick, at the Cock of Arran, and in numerous sections between Brodick and Whiting Bay. Gunn, in the table quoted on p. 176, classified the beds into four divisions, which he described in the Memoir on North Arran. His description applies well to these rocks in the southern part of the island. The upper bed, the light-coloured, yellowish, carious sandstones, may be seen in Ballymichael Glen, in the upper part of the burn to the south of that glen, and to the south of Whiting Bay. The underlying red sandstones, with some conglomerate, are exposed at Gortonallister, between Whiting and Lamlash Bays. The rock there is a thick, massive, fine-grained red sandstone, which rests on a softer, more argillaceous sandstone, and has no special false bedding and no interstratified conglomerate. The rocks in the same division are shown north of Lamlash in the Lag a Bheith Burn, which lies

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to the west of the road from Brodick to Lamlash. The rocks are of a brick-red soft sandstone, and the exposures which I examined there included no conglomerate.

Beneath the subdivision composed of the sandstone occur the conglomerates, which are well known from their excellent exposures on the beach and in the cliff at Brodick. The rock consists of beds of quartz conglomerate and breccia, interstratified with layers of false-bedded red sandstone. Some of the conglomerate bands are full of dreikanter, and pebbles with flattened surfaces and rounded edges; and some of the layers contain numerous wind-etched pebbles of vein quartz. The matrix of the layers containing these stones is composed of well-rounded wind-worn sand grains. Some parts are intensely false-bedded, and some layers had been broken up before the next sheet of gravel was deposited.

The section includes some broken-up seams of clay, and some of the larger clay pebbles have been altered into masses of a fine hæmatitic clay. The conglomerate includes boulders a foot in diameter, and some of the large quartzites, which have been derived from the Old Red Sandstone conglomerates, are as spherical as cannon balls.

This Brodick conglomerate is local in distribution, but, as described by Gunn, the horizon is represented in western Arran by a pebbly band exposed a few yards south of the deer fence across the Machrie Water. The pebbles are small, ranging up to 2 inches or so in diameter. They are wind-facetted, like those at Brodick.

The lowest subdivision of the Lower Division consists of the Brodick freestones, which are exposed in the quarry at Brodick, at the back of Invercloy cottages. The rock is a false-bedded sandstone full of sand grains, which are as well rounded and polished as those of any modern desert. The felspar grains are often fresh, showing that they were deposited under an arid climate. The false bedding is often sharply cut off above by a horizontally bedded sandstone. The false bedding in this quarry is less developed than in the dune-like accumulations of the Ballochmyle quarries, in central Ayrshire; but that occurs elsewhere in Arran, and is shown in the photograph of the sandstones south of Corrie, published in the Memoir on North Arran (pl. vii.).

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4. The Classification of the Upper Red Rocks.

The foregoing account of these rocks shows that the Upper Red Sandstones of southern Arran include two very different groups of rocks. The Upper Series consists of various sandstones, some of which are blue and calcareous, also red shales, earthy limestones, marls, and layers of calcareous nodules. This series of beds presents the characteristics of aqueous deposits, and some of the marls are crowded with minute calcite rhombs, and were probably laid down under lagoon conditions.

The red marls are so similar to those of the English Keuper that hand-specimens are indistinguishable.

The beds of the Lower Series are extremely different lithologically. They are chiefly sandstones, with only the most insignificant deposits of clay. False bedding is often strongly developed, and is of a dune type. The layers of white mica, blue sandstone, and marls of the Upper Division are absent; and one subdivision consists of coarse quartz conglomerate, which is unrepresented in the Keuper. The rounded form of the sand grains and the typical character of the materials show that the great bulk of the Lower Division was laid down on land under desert conditions. The quartz conglomerates must have been spread by floods of water, though the pebbles thus distributed must have been subsequently exposed for a long time to wind action.

The lithological differences between the rocks of the Upper and Lower Series is the result of the different geographical conditions under which they were deposited. The Lower Division consists mainly of cemented desert sands; the Upper Division consists of beds laid down by water as lagoon deposits or in lake pans, with occasional sub-ærial layers.

The lithological agreement of the upper beds with the English Keuper is so close that Gunn appears fully justified in referring it to the Keuper, of which it appears to be the only representative in south-western Scotland. His reference, however, of the Lower Division to the Bunter seems to need revision. The Bunter beds are represented in Cumberland, Dumfries, and the Isle of Man by the St. Bees Sandstone, of which the Scottish representative is the Annan Sandstones of south-eastern Dum-

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friesshire. The Lower Red Sandstones of Arran appear to differ fundamentally from those deposits. The St. Bees Sandstone is an aqueous deposit, which contains layers of sharp, angular quartzose and felspathic sand, and seams full of white mica. False bedding is not extensively developed. The sandstones are interbedded with layers of red shale, many of which were deposited in channels cut by contemporary streams.

The lower beds of Arran are, on the other hand, terrestrial deposits. As remarked by Sir Archibald Geikie and Gunn, they closely resemble the Ballochmyle Sandstone of Ayrshire, which agrees in its physical characters with the Penrith Sandstone of the north-west of England. The Brodick Sandstones of Arran are probably Lower Permian.[2]

That the marls at the top of the series, the Levencorroch Marls, are Keuper may be safely accepted; but the correlation of the intermediate beds is more doubtful. Alternative courses are available. If we follow Gunn in accepting two divisions of the Arran series, then all the Permians would belong to the Lower Permians, and all the Triassic beds to the Keuper; the Upper Permian and Bunter would be unrepresented. There is, however, no clear evidence of any great gap in the series.

As Arran was outside the area most disturbed by Permian earth movements, the Keuper may conceivably have been deposited in apparent conformity with the lower beds; and owing to the resemblances between both groups of rocks the separation between them may never have been conspicuous, and it may have been obscured by the igneous intrusions. Even in districts undisturbed by igneous activity, the evidence of unconformities in these red rocks is often obscure. Thus, in the Geological Survey Memoir on the country around Ollerton (Mem. Geol. Survey, Eng. and Wales, Sheet 113, 1911, p. 15), Mr. J. B. Hill claims that there "is an unconformity between the Bunter and the Permian"; whereas Dr. R. L. Sherlock, another of the authors of that Memoir, holds that those formations are there conformable (*Quart. Jour. Geol. Soc.*, vol. lxvii., 1911, p. 76).

[2] Gunn (1898, p. 272) referred to some lavas and a fossil, which Mr. Kidston identified as Carboniferous or Permian from the Red Sandstones at the head of Sliddery Water; but subsequently fossils found by Gunn were identified by Peach (Gunn, 1898, pp. 113-114) as belonging to the Coal Measures.

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The alternative view is that there was a continuous deposition in Arran throughout Permian and Triassic times. This view is supported by the absence of any discovered unconformity. The characteristic difference between the British Keuper and Bunter is that the Keuper consists of marls and the Bunter of sandstones, and the Trias of Arran shows the same feature. If this be more than a coincidence the Auchenhew sandstones and shales would represent the Bunter. The chief representative of the Bunter in Cumberland, Dumfriesshire, and the Isle of Man is the St. Bees Sandstone; and that distinctive rock does not occur in Arran. The nearest non-Scottish Bunter deposits are beside Belfast Lough; they are described by Lamplugh (1904, p. 19) as cross-bedded sandstones and semi-indurated sand, and (*ibid.*, p. 20) as white, brown, and light purple sandstone, often micaceous, with thin partings and blotches of red marl or shale; and the sandstone is massive or flaggy, and is often cross-bedded. Those soft Bunter sandstones of Belfast may be represented in Arran by the Auchinhew sandstones. The characteristic upper Permian rock around the basin of the Irish Sea is the Gypseous Shale, which is absent from Arran; but the Ballymichael and Lamlash sandstones may represent this division. Arran lacks both the gypsum and salt, which are the chief economic products of the Permo-Triassic series further south; and Arran lay so far north of the great basin of Permo-Triassic sedimentation around the Irish Sea that it had a less varied and thinner series of deposits.

The following classification is suggested for the Upper Series of Red Sandstone in Arran:—

			Approximate Thicknesses.
Rhaetic.		Black shales and grey limestones in Ard Bheinn.	
Trias,	Keuper,	Greenish gray marls (near Derenenach),	—
		Red shales with green layers and thin sandstones. Torr nan Uain,	60 feet.
		Levencorroch marls—with calcareous sandstones, shales with layers of nodular and earthy limestones,	200 ,,
	? Bunter,	Auchenhew shales—Red and green shales with thin sandstones,	350 ,,
		Auchenhew sandstones,	200 ,,
		Bennan shales with sharp yellow and blue sandstones,	150 ,,
			960 feet.

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Permian,	? Upper Permian,	Ballymichael sandstones. Lamlash sandstone. Coarse red sandstone slightly false bedded, occasional conglomerate; Corrygills, Lag a Bheith Burn, south of Brodick, Gortonallister, Lamlash, and Whiting Bays.
	Lower Permian,	Brodick Breccia. Layers of coarse quartz breccia with facetted pebbles and coarse wind-rounded sand-grains; the layers alternating with coarse red false bedded sandstone. South shore of Brodick Bay, Machrie Water. Brodick freestone. False bedded, brick-red sandstone with very rounded wind worn-grains. Brodick, Corrie, Cock of Arran.

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No. XV.—On the Boundary between the Upper and Lower Divisions of the Red Rock Series near Whiting Bay and in the Sliddery Water, Arran.

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[Read 14th May, 1914.]

Introduction.

The observations recorded in this paper were made at the suggestion of Professor J. W. Gregory, and were merely meant to supplement his work (see these *Transactions*, vol. xv., page 174) on the Permian and Triassic rocks of Arran by describing sections which, at the time of his research, he was unable to reach. The paper, therefore, does not pretend to be much more than a record of field work. It is almost a literal transcript from field notes, with the addition of a few notes on the petrological character of the rocks.

Besides being stratigraphically somewhat indefinite, the boundary between the Upper and Lower Divisions of the Red Rock series is almost always further obscured by igneous intrusion and faulting in sections where the transition might reasonably be expected to occur. The southern half of Arran is riddled by an extraordinary complex of igneous rocks, consisting of "felsite-basalt" composite sills, "gabbro-granophyre" mélanges, teschenites, quartz-porphyries, and quartz-felsites, with multitudes of basalt dykes. The igneous rocks probably occupy almost half the total area of the southern part of the island. It is not strange, therefore, that the exact nature of the junction between the two divisions remains uncertain, although, as shown by Professor Gregory, the petrological contrast between the rocks at the top and bottom of the series is very marked.

On the new 1-inch colour-printed geological map of Arran (Geological Survey, 1910) the boundary between the two divisions starts from the sea on the east coast a little to the south of Largybeg Point, where it is represented as free from igneous rock.

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Fig. 1.

Fig. 2.
Intrusive Dyke and Rock Arch at Largybeg Point.

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Striking to the N.N.W., towards Largiemore, the junction is represented as being occupied by a thin sill of teschenite, which, however, gives place to a thick composite sill in the V-outcrop of Glenashdale. This sill continues for three-quarters of a mile to the north of Glenashdale, where, near Borrach, the junction is again free from igneous rock for the distance of a quarter of a mile. Unfortunately no section is visible at this point. From here the boundary swerves to the north-west, and is occupied by a composite sill, which ultimately merges into the great igneous complex of Tighvein. In this locality the boundary turns to the south-west, but the two divisions are separated for a distance of several miles by a broad strip of igneous rock, which is never less than half a mile wide, and frequently much wider. The junction is again free from igneous rock for a distance of a mile and a half between High Clauchog and Bennecarrigan. The sections here are described by Professor Gregory. The junction now takes a general north to south direction, and the two divisions are represented as being separated by a fault, Igneous rocks reappear between Tormusk and Clauchan Glen. but for the distance of a mile and a half near Ballymichael the junction is again free from igneous rock, but is partly made up of a problematic fault. This part of the boundary has also been described by Professor Gregory. At Ballymichael the rocks pass under the raised beaches and alluvium of the Black Water, and although isolated areas of both divisions with igneous rocks occur rising through the recent deposits, observation of the junction is no longer possible.

Description of Sections.

The sections visited by me will be described in order from east to west.

(1) Section along the shore from Creag Dubh (southern horn of Whiting Bay) to Dippin Head. Ordnance Survey, 6-inch scale quarter-sheet, Buteshire (Arran), 255 S.W.

Creag Dubh consists of a sill of fine-grained "blue basalt,"[1] resting upon, and overlaid by, sandstone dipping 20° to 30° due west. The section from here to Largybeg Point is in thin-

[1] This is a spherulitic or granophyric dolerite, probably a hybrid rock.

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bedded red sandstone, which contains an occasional quartz pebble and local sprinklings of fragments of green and brown shale. The dip is 20° to 30° slightly south of west, and the strike a little east of south, so that higher beds are slowly exposed as the observer walks southward along the coast. Some of the sandstones are coarser and grittier than others, and many have a cement of whitish, decomposed felspathic material. Others have a calcareous or dolomitic cement, and in these rocks occurs a peculiar carious weathering, which may be seen at many places along the section, notably at Largybeg. This feature is often especially well developed where the sandstone is hardened by igneous action. The hollowing is sometimes replaced by a nodular weathering, resulting frequently in clavate or mushroom-shaped projections. This weathering is due to an irregular distribution of the calcareous cement, or to variations in its composition, rendering it more liable to solution in some places than others. The red colour is discharged, and the sandstones become a dull white or yellow, near the numerous dykes which penetrate the rocks.

A thin band of bluish shale appears in the small cove just north of Largybeg Point. At Largybeg Point itself the section is diversified by a 15-foot sill of basalt, and by a bed of conglomerate 6½ feet thick. The full section across the Point from south-east to north-west is as follows, in descending order:—

(*a*)	Thin-bedded red sandstone,	42 feet +
(*b*)	Basalt sill,	15 ,,
(*c*)	White gritty sandstones, with line of local unconformity and rock arch,	33 ,,
(*d*)	Coarse grit with bands of conglomerate,	9 ,,
(*e*)	Conglomerate,	6½ ,,
(*f*)	Carious white sandstone,	9 ,, +

The last bed abuts against a thick basalt dyke hading 45° east, beyond which is the sea. The sedimentary rocks are intersected by three basalt dykes, one of which forms an outstanding wall (Fig. 1, Plate XXVI.), and the others trench-like depressions. A curious rock-arch, excavated in bed *c*, now stands on the 10-foot raised beach well above high-water mark (Fig. 2, Plate XXVI.). This section is shown in detail in Fig. 1, text.

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The pebbles in the Largybeg conglomerate consist mostly of white and pink vein-quartz, with quartzites similarly coloured, and a few of red felspar-porphyry, flinty quartz-felsites, grey mudstone, red sandstone, and chert. The igneous and quartz pebbles range between one or two inches in diameter, and are mostly of a well-rounded shingly type. A few pebbles, however, show distinct facetting in three or four directions, with a flat base, and are unmistakably dreikanter. Nevertheless, the edges of these are frequently well rounded, and they have evidently suffered some water erosion in addition to their original wind-facetting. The igneous and quartzitic pebbles, whatever their present shape, are of distant origin. On the other hand, the sandstone and mudstone pebbles, which are large and angular, are clearly of local origin. The matrix is a coarse sandstone consisting mainly of rounded and polished grains of quartz and an occasional cleavage fragment of fresh felspar, embedded in a whitish, decomposed, felspathic matrix.

The whole aspect of the conglomerate suggests that it represents an accumulation of pebbles and sand brought together by the occasional rain-bursts which occur in a desert or sub-desert region. This would account for the mingling of rounded shingly pebbles and angular dreikanter in a matrix of desert sand.

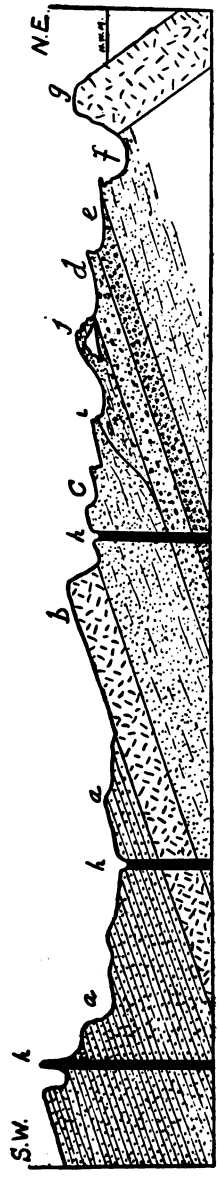

Fig. 1.—Section across Largybeg Point. Length of section about 440 feet (see p. 190, text). (*a*) Thin-bedded red sandstone; (*b*) Basalt sill; (*c*) White sandstone; (*d*) Coarse grit with bands of conglomerate; (*e*) Conglomerate; (*f*) Carious white sandstone; (*g*) Thick basalt dyke; (*h*) Basalt dykes; (*i*) Line of local erosion; (*j*) Rock-arch on raised beach.

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To the south of Largybeg Point the dip of the strata becomes nearly parallel to the shore, and averages 10° to 15° south-west. For a hundred yards the section is then covered by shingle, broken only by one small outcrop of sandstone maintaining the same dip. Beyond the shingle comes the outcrop of a small basalt sill, which has protected the strata beneath it. The latter are sandy marls, interbedded with sandstone, and are bent into a flat anticline, whose northern limb dips to the north, and is opposed to the dip of the sandstone of Largybeg Point. The slight flexure and change in direction of dip is probably due to the influence of the little sill, but it is curious that a change of dip should come close to the point where, according to the 1-inch map, the junction of the sandstone and marl divisions takes place.

From this point until the escarpment of the great Dippin sill of teschenite or crinanite[2] sweeps down to the shore, the rocks are covered by shingle. The lower contact of the sill is exposed at the north end of the cliff, and the igneous rock rests upon hardened and burnt shale, dipping about 10° to the north. The south-westerly dip is resumed, however, to the west of Dippin at Torran Clachach, and to the south-west of the sill at Kildonan. It is probable therefore that the small flexure at Dippin is local and due to igneous intrusion.

It is unfortunate that the critical junction in this section, which occurs a little to the south of Largybeg Point, should be so largely obscured, but what evidence there is available goes to show that the transition between the two divisions is gradual, and that there is no marked discordance.

(2) Section on hillside south of Glenashdale, and in Glenashdale. Ordnance Survey, 6-inch scale quarter-sheet, Buteshire (Arran), 255 N.W., 255 S.W.

The sections occur in a little stream discharging into Glenashdale Burn near the site of the Chapel (see sheet 255 N.W.), and in a small gorge unmarked on the 6-inch map, to the east of Torr an Loisgte (sheet 255 S.W.). Ascending from Glenashdale horizontally-bedded red sandstones, cut by a N.W. to S.E. basalt dyke, are first encountered. Upon these rests a thin sill of grey felspathic basalt, which forms a prominent escarp-

[2] Tyrrell, *Geol. Mag.*, July, 1913, pp. 305-9.

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ment. Above this a second grass-covered terrace and escarpment leads up to a second sill of "blue basalt,"[3] but this is resting on horizontal red and green shales and marls. This section appears in the unmarked gorge east of Torr an Loisgte. There are no further sections until, to the south, the escarpment of the main Dippin sill is reached, cut by a composite pitchstone dyke.[4] In this section also the junction between the two divisions is masked, and basalt sills appear at or near the boundary. Both rocks are horizontally bedded, and there appears to be no discordance between them.

In Glenashdale itself the junction between the two divisions is occupied by a thick composite sill. The first considerable fall, going up Glenashdale Burn, is over a hard bed of sandstone overlaid by softer shaly material. The second fall marks the outcrop of the large composite sill in Glenashdale Wood.

The fall is divided into a lower leap of about a hundred feet, and an upper of fifty feet. The lower leap is over a broad transverse dyke of basalt, and the walls of the gorge are in sandstone; the upper leap is over the outcrop of the sill, but at its foot is another transverse dyke. Above the sill, whose upper contact is not visible, the true Triassic marls and shales are occasionally seen in the course of the burn (see section, Fig. 2).

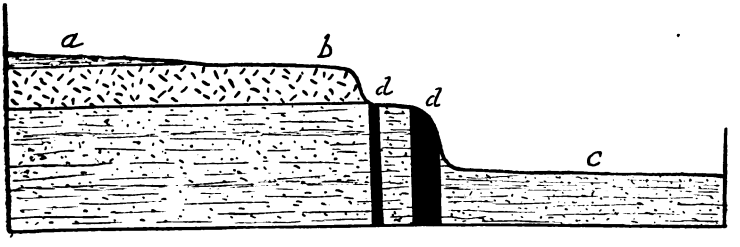

Fig. 2.—Section along Glenashdale Burn, over falls (text, p. 193). (*a*) Shales and Marls; (*b*) "Felsite-basalt," composite sill; (*c*) Red sandstones with occasional shaly bands; (*d*) Basalt dykes.

(3) Section in stream ⅓ mile E. of Cnoc Mor (867 feet O.D.), N. of Glenashdale Wood. Ordnance Survey, 6-inch scale quarter-sheet, Buteshire (Arran), 255 N.W.

[3] This dense, hard, blue, basalt-like rock turns out in thin section to be rich in quartz, but the very fine-grained groundmass appears to be quite basic. It is probably a hybrid rock.

[4] A. Scott, *Trans. Geol. Soc., Glasgow*, Vol. xv. Pt. 1, 1914, p. 22.

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Starting from the path on the north side of Glenashdale Wood, a glaciated exposure shows fine-grained "blue basalt" (hybrid rock of composite sill), weathering in rounded masses with exfoliation. The bed of the stream is occupied for some distance by a dyke of porphyritic basalt. The composite sill is overlaid by soft whitish and buff thin-bedded sandstones, probably red sandstone with colour discharged by the igneous contact. In these rocks there is a horizon characterised by chocolate-coloured, ferriferous, micaceous sandstones, a band of which forms a small fall. Above these are a few hard quartzitic bands, which form smooth platforms in the stream-bed, and alternate with thin-bedded soft red sandstones. Before the base of a second sill is reached the sandstones become very soft and marly, and are intercalated with shales and marls. The type is gradually changing to the "Triassic marls and shales." Above the second sill the sedimentary rocks become increasingly marly, but still contain a few bands of harder red sandstone. Typical "Triassic marls" and shales, however, form the whole of the section before the third and last sill comes on. In these shales and marls there is a dyke-like mass of basalt with a steep hade to the west, which resembles the contact rock of the basalt-felsite composite sills. It is exposed in the stream-bed, but apparently terminates in a vertical direction, since the horizontally bedded shales and marls are seen without a break in the bank where the dyke should appear (see Fig. 3).

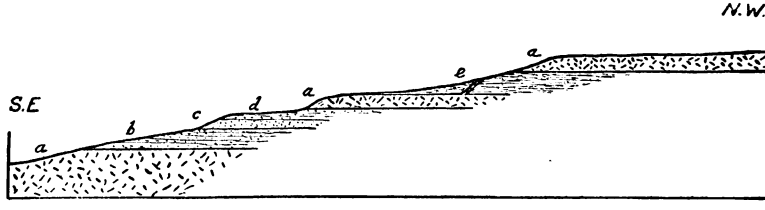

Fig. 3.—Section along the burn one-third of a mile east of Cnoc Mor, north of Glenashdale Wood. (*a*) "Felsite-basalt," composite sills; (*b*) Thin-bedded red sandstone; (*c*) Chocolate-coloured ferriferous sandstone; (*d*) Quartzitic sandstone; (*e*) Shales and marls. Length of section half a mile.

This section, which is perhaps the best of those that traverse the junction between the two divisions of sedimentary rocks, shows pretty clearly that the transition is perfectly gradual,

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and that there is no discordance. The lower sandstones become softer and more argillaceous on being traced upwards, and are intercalated with bands of marl and shale in increasing numbers until they constitute the whole section.

(4) Section in the Allt Garbh, Borrach, 1½ miles west of Whiting Bay. Ordnance Survey, 6-inch quarter-sheet, Buteshire (Arran), 255 N.W.

Starting from the path at the north-eastern corner of Glenashdale Wood, a blue "basalt-felsite" composite sill is first seen, the upper contact of which occurs at a small fall a few yards above the path. The sedimentary rock from this point right up to the main N. to S. fence, round Borrach, is a thin-bedded red sandstone, with occasional bands of harder chocolate-coloured sandstone, whitish sandstone, and ordinary red sandstone, which give rise to small falls. Rocks resembling the Triassic marls and shales occur immediately above the N. to S. fence, where a crag is marked on the 6-inch map. These are very soft, grey, green, and red sandstones and sandy shales, with some marly material too coarse and gritty to be quite typical marls. These are horizontally bedded, and occur above and below a thinning tongue of igneous rock from a thick sill to the west. The sill makes a twenty-foot fall, but above the fall, owing to steepness and dense wood, the rock in the gorge of the burn is inaccessible till Creag Bhan is reached. As far as can be seen the rocks are mainly red marly sandstones.

At the gorge of Creag Bhan is a rather involved mass of igneous rocks, including spherulitic felsite, "felsite-basalt" composite sill, and several basalt dykes, with at least two demonstrable faults. The true Triassic marls and shales, brick-red, tea-green, and ash-grey, are seen in Creag Bhan. They are interbedded with soft marly sandstones and some thick posts of whitish and chocolate-coloured sandstone. Up to the igneous rocks of Creag Bhan the dip does not depart sensibly from the horizontal. The intrusion and the faulting, however, result in various inclinations, different on opposite sides of the gorge. There is nothing to indicate discordance between the marls and the underlying red sandstones.

One-eighth of a mile above Creag Bhan the spherulitic felsite of that locality passes under horizontal red sandstone and shale,

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and the sedimentary rock upstream of this point is a thin-bedded chocolate-coloured shale. Thence the stream passes into the extensive felsite mass of Loch na Leirg.

(5) Sections in the Sliddery Water and Allt Burican, near Burican. Ordnance Survey, 6-inch scale quarter-sheets, Buteshire (Arran), 254 S.W. and 254 N.W.

In the Sliddery Water, 200 yards above Glenrie Bridge, a junction of pink banded felsite is seen against sedimentaries. The nearly horizontal joint-planes of the igneous rock curve up until they become nearly vertical at the junction, which may be a fault-plane. The sediments here consist of chocolate, white, and reddish sandstones, interbedded with a little true marl, and other marls of sandier type.

The Burican pitchstone forms a ledge, smothered in ferns, between the road and the Sliddery Water above the felsite junction. It slopes towards the river, and has a visible thickness of at least twenty feet. It seems probable that it is the upper part of the banded felsite seen at the above-described junction.

At the right-angle turn in the stream, 200 yards higher up, the sediments are rather hard, whitish, or yellow sandstones dipping downstream at 10° to 20° south. They are cut by two N. to S. dykes, and are not interbedded with shaly material. These sandstones weather with a rough but hardly carious surface. They are in beds about one foot thick, and although they are sometimes thinner-bedded they do not pass to shaly types. I take it therefore that these belong to the lower sandstone division, and the exposure containing marls, at the felsite junction, as belonging to the upper marly division. The junction in this case is occupied by a felsite-pitchstone sill, and should be drawn about a quarter of a mile further to the north than it is represented on the 1-inch Geological Survey map.

The Burican section.

The section commences at the forking of the Allt Burican about three quarters of a mile above Burican. Nothing can here be seen of the fault, which, according to the Geological Survey map, crosses the stream near the fork. At a right-angle turn below the fork are exposures of thin-bedded and false-bedded red sandstone, dipping due west at about 10°. A small gorge

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along the strike occurs below this, and is crossed by two thin basalt dykes, causing a cascade.

At the "hairpin bend" lower down, red and green sandy shales and marls are seen interbedded with sandstone. These rocks appear at intervals in the stream-section down to nearly opposite Burican. Here, however, after a blank interval, a whitish, thick-bedded sandstone occurs dipping 20° to 30° downstream. This looks very much like the white rough-weathering sandstone of the Sliddery Water. Between the ford and the footbridge opposite Burican there are bands of red sandy marls interbedded with white and red sandstone, the latter having distinct carious and nodular weathering. Below the footbridge occur typical soft, unctuous red marls, two feet thick, interbedded with red sandstone in a small exposure. Below this the section for a long way is in pink felsite.

Near the 254 feet O.D., about 250 yards above Glenrie Bridge, the only indication of a fault is seen in an exposure of red marls, interbedded with carious sandstone, with nearly vertical dip. Below this the section passes again into felsite, which continues to the junction with the Sliddery Water. According to the Survey map, the Burican Burn runs along the line of a fault separating the lower sandstones from the upper marly series, but of a fault direct evidence was obtained at one point only, in spite of good exposures. It is more probable therefore that the fault crosses the stream at an angle, and does not run along it as shown in the Survey map.

Conclusions.

In spite of the occurrence of igneous rocks at or near the junction of the two divisions, and the obscurity of many of the sections, there seems to be ground for asserting that the evidence tells, as far as it goes, in favour of *continuous sedimentation* from the Lower to the Upper Division. In the most favourable sections there is no sign of a break or unconformity in the series, or a discoverable gap or non-sequence. On the contrary there are signs that the rocks of the Lower Division pass by gradual transition into those of the Upper Division, although the contrast between the sandstones characterising the

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major part of the Lower Division and the marls at the top of the Upper Division is quite sharp. Near the junction the sandstones begin to be interleaved with shales and thin marls, the intercalations of which so increase in number and thickness that they soon constitute the bulk of the sections. True, marl is not at all abundant near the junction of the two divisions, but the shales are frequently calcareous, as are also the sandstones. Some beds partake of the properties of all three types, that is, they are argillaceo-arenaceous sediments with a notable amount of calcareous cement.

On the other hand, unconformities or breaks of any kind are difficult to detect in these red rocks, quite apart from the obscurities introduced by igneous action and by lack of clear sections. If we adopt the view that the Brodick Freestone and Breccia belong to the Lower Permian, and the Levencorroch Marls to the Keuper (see Professor Gregory's paper, this volume, p. 186), and that in Arran sedimentation was continuous throughout Permian and Triassic times, we have to find room in the series for the Upper Permian and the Bunter. The Lamlash and Ballymichael Sandstones are in the right stratigraphical position to be assigned to the Upper Permian, and the Bennan Shales, Auchenhew Sandstones, and Auchenhew Shales to the Bunter (see Professor Gregory's paper, this volume, p. 186), but in the circumstances any such correlation can only be regarded as extremely tentative. If the Lamlash and Ballymichael Sandstones are Upper Permian they have a totally different petrographic character to the gypsiferous shales which characterise that horizon around the basin of the Irish Sea; but the description of the Bunter Sandstones of the Belfast district by Lamplugh[5] agrees fairly well with the rocks doubtfully assigned to that horizon in Arran, as is shown in the following table:—

Bunter, Belfast.	*Bunter(?), Arran.*
Cross-bedded sandstone.	Soft red thin-bedded sandstone.
Semi-indurated sand.	Hard quartzitic sandstone, white sandstone.
White, brown, and purple sandstone, often micaceous with thin partings and blotches of red marl or shale.	Chocolate-coloured micaceous sandstone.
	Red, brown, green, and blue shales. Red, green, and grey marls.

[5] *Mem. Geol. Sur., Ireland,* "Geology of the Country around Belfast" (1904), pp. 19-20.

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EXPLANATION OF PLATE XXVI.

FIG. 1.—Wall-like dyke rising through thin-bedded red sandstones below junction of the Upper and Lower Divisions of the Red Rock Series, Largybeg Point, Arran.

FIG. 2.—Rock arch on raised beach, Largybeg Point. The arch has been cut in the white sandstone (bed (*c*) of Fig. 1, text). Note the rough carious weathering of the sandstones.

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No. XVI.—The Hurlet Sequence in North Ayrshire. By Peter Macnair, F.R.S.E., F.G.S.

[Read 14th May, 1914.]

Contents.

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III. Renfrewshire Sections, { Hurlet Nethercraigs, Howwood, Bridge of Weir, Glenlora and Roebank. Auchenback, Levern at Neilston, Netherton and Duniflats.
IV. Ayrshire Sections, { Lugton, Hesselhead, Broadstone and Dockra Quarries, Gurdie Railway Cutting, Paduff Glen, Hindog Glen, Auchenskeith to Gameshill.
V. Stratigraphical Considerations.
VI. Palæontological Considerations.
VII. Physical Condition of Deposition.
VIII. Summary of Conclusions.

I. Introduction.

The purpose of this paper is to attempt a correlation of the limestones of North Ayrshire with those of the Hurlet section, and incidentally to point out certain palæontological evidence which may be of some assistance in identifying the Hurlet sequence in the West of Scotland with that of Fife and the Lothians. It is scarcely necessary for me to remind you that Scottish geologists headed by the Survey have long been endeavouring to correlate the Lower Carboniferous Limestones of Fife, the Lothians, and in general the limestone of the Carboniferous Series of Scotland with what has been chosen as the type section at Hurlet. In fact, as you are well aware, the officers of the Survey have used the Hurlet as a datum line for the separation of the Calciferous Sandstone series from the Lower Limestone series. In a paper contributed to the society along with Mr. Conacher last year we stated that in our opinion there is no essential break at this horizon in our district such as exists in the Lothians, and we dealt with all the beds seen in the

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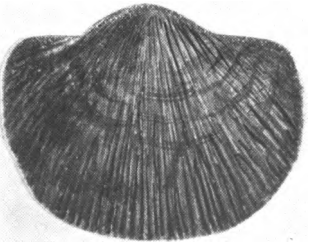

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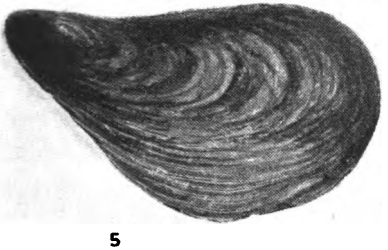

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6

Brachiopods and Lamellibranchs, from Shale between Hurlet Coal and Hurlet Limestone, Howwood, Renfrewshire.

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Hurlet district as one series. My recent examination of the Ayrshire rocks has not led me to alter this opinion in any way. The strata under consideration, then, will include all that lie between the volcanic rocks at the base and a marine band, whose position is about 60 feet above the Johnstone Clay band ironstone in the Hurlet district.

It might be asked at the very outset by some, why has the Hurlet district been chosen as the type section of these deposits? And the answer would not be difficult to find—it simply being that it was amongst the earliest and best known sections to be studied by geologists and mining engineers; and naturally when they examined any new section they would at once ask the question, how are they related to the Hurlet section? Not till a definite correlation of these rocks has been made will it be seen whether geologists have been justified in selecting the Hurlet section as typical of these deposits in the West of Scotland. Of course, it would possibly not matter much what district had been taken as typical for correlation purposes, as recent evidence tends to show that the limestones of the West of Scotland are liable to rapid lithological and palæontological alterations.

The subject will be treated in the following manner:—First, a summary will be given of the principal stratigraphical and palæontological feature of the Hurlet sequence as seen in the type district, then the Ayrshire border will be approached by way of Nethercraigs, Howwood, and Bridge of Weir through the Lochwinnoch gap, and by Auchenback, Neilston, and Duniflats through the Neilston gap. In these sections important links in the correlation of the Ayrshire sequence with that of Hurlet will be described. The remaining section of the paper will deal with certain stratigraphical and palæontological considerations and with the physical conditions under which the rocks have been formed.

An inspection of a geological map will show that the Lower Limestone series of Renfrewshire are extended into Ayrshire along two wedge-shaped areas separated by the Calciferous lavas. The most southerly lies between the volcanics of the Fereneze Braes on the one hand and the Neilston Hills on the other, and extends from Barrhead to Lugton, the gap between these

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two ranges of hills being occupied by the Lower Limestone series, which at certain places is faulted against the older lavas, while at others it rests unconformably upon them. The more northerly area lies between the Neilston Hills and the Lochwinnoch Hills, and extends from Howwood to Beith, the relationships of the limestones to the lavas being similar to that in the southern area. These two areas coalesce round the south-west of the volcanic ridge lying between the two gaps, and form the northern edge of the Carboniferous basin, which has Dalry for its centre. In the neighbourhood of Lugton and Beith the limestones have been extensively quarried, and have yielded West of Scotland geologists a remarkably rich series of fossils. Unfortunately many of these quarries are now filled up, or are rendered in other ways inaccessible. Still, the sections available are of the greatest value in working out the sequence. All round the margin of the basin there are also a number of quarries which help to elucidate the structure of the ground. On the western side of the basin there occur numerous additional stream sections, such as those seen in the Paduff Burn and the Rye Water, the section in the former being especially clear and complete. Valuable sections, both natural and artificial, are also exposed in the centre and eastern side of the basin, including those seen in the Pogree Burn and the Lugton and Dusk Waters, and the quarry sections extending from Auchenskeith by Auchenmade and Auchentiber to Gameshill and Stewarton. We shall first, then, examine the section in the Renfrewshire area, and then proceed round the western and eastern margins of the Ayrshire basin.

II. Literature.

The literature upon the subject is somewhat meagre. The first attempt at a detailed description of the stratigraphy of the North Ayrshire district is that by Robert Craig, published in our *Transactions* in 1869.[1] This was the forerunner of a series of papers which were to prove of the utmost value in the investigation of the geology of this district. In this paper he gives an outline sketch of the geology of North Ayrshire, and

[1] Sketch of the Carboniferous Basin of Dalry, Ayrshire. *Trans. Geol. Soc. of Glasgow*, vol. iii., p. 271.

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a perusal of it will show that he had already arrived at a knowledge of the general sequence of the strata in that region. He differentiates out the limestones of the Beith Quarries into lower and upper beds separated by 40 feet of Divisional Shales, the lower beds being seen at Broadstone and the upper at Hillhead Quarries. He also described various sections exposed in the Rye Water, Paduff Glen, Auchenskeith, Auchenmade, and other localities.

In the two succeeding papers[2] Mr. Craig dealt in detail with the stratigraphy and palæontology of the lower and upper members of the basal limestones as seen at Broadstone, Dockra, and the other quarries near Beith, making a correlation of them with other exposures seen round the sides of the basin. A fourth paper[3] dealing with the fossiliferous strata lying between the lower and upper limestones in the Beith and Dalry district then appeared. This includes an account of the limestones lying above the Dockra lime, as seen in Kersland Glen, and of the strata lying between the Main Clay ironstone and the Main Coal. His last paper, bearing upon the Lower Limestone series, gave an account of the section exposed in the new Kilbirnie branch of the Lanarkshire and Ayrshire railway at Gurdie.[4] In it he shows how the stratigraphical and fossiliferous characters of the strata west of the Pogree Burn had been closely anticipated in his previous paper. The great value of Mr. Craig's papers and fossil lists to the stratigrapher lies in the fact that he made as complete a list of fossils as possible, carefully noting the particular bed in which they occurred. He was not content, as unfortunately many of our collectors were, to simply state the quarry or the district where they were gathered, a method of localisation which has rendered many of our most valuable collections nearly useless for zoning or stratigraphical purposes. In reading through Mr. Craig's papers I cannot find

[2] On the first appearance of certain fossils in the Carboniferous Strata around Beith and Dalry. *Op. cit.*, vol. v., p. 36.
On the Fossils of the Upper Series of the Lower Carboniferous Limestones in the Beith and Dalry Districts of North Ayrshire. *Op. cit.*, vol. vi., p. 1.

[3] On the Fossiliferous Strata lying between the Lower and Upper Limestones in the Beith and Dalry district. *Op. cit.*, vol. vii , p. 86.

[4] Notes upon a Cutting in the new Kilbirnie branch of the Lanarkshire and Ayrshire Railway. *Trans. Geol. Soc. of Glasgow*, vol. ix., p. 64.

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that he ever made any attempt to correlate the Ayrshire sections with those of the Hurlet district. Had he been inclined to do so he probably felt the great difficulties that were presented by the apparent want of resemblance in the two areas.

Mr. Hugh M'Phail published an important paper in the year 1869 on the Carboniferous sections of the Levern Valley, Renfrewshire, in which there is an account of the Hurlet series, but nothing is said of their continuation into Ayrshire.[5]

In 1872[6] the Survey Memoir, in explanation of Sheet 22, appeared, and as the area under discussion is wholly included in that sheet, we extract the following brief account of it which is given in the section dealing with the Carboniferous Limestone series in the Dalry, Beith, and Auchenskeith districts. It gives a good idea of the position taken up by the Survey, as we do not know of any other work of theirs that has been published. The lowest limestone is best seen in the numerous large quarries to the south-east of Beith, but admirable sections of it are also to be found in the Howrat Quarries above Kilbirnie, as well as those along the course of the Dusk Water between Auchenskeith and Auchenmade. In several places it is divided into two massive seams by an intercalated band of sandstone or shale with a thin coal and fireclay. The thickness of the two seams together with the intervening shales, &c., may be taken to be about 100 feet in the Beith district, and perhaps about 60 feet at Auchenskeith. Here follows a list of characteristic fossils from these limestones. From this it will be seen that no attempt had been made by the Survey at a detailed correlation of the Ayrshire rocks, not to speak of identifying them with the Hurlet sequence. In another part of the same Memoir, however, the limestones of Thorntonhall and East Kilbride are noted as having a general resemblance to the grey Lower Limestone of Lugton, consisting of a number of thick beds and thin bands of variable quality separated by thin partings of calcareous shale. We hope to be able to show in the course of this paper that this surmise was probably correct.

[5] The Carboniferous Sections of the Levern Valley, Renfrewshire. *Op. cit.*, vol. iii., p. 254.

[6] Memoirs of the Geological Survey of Scotland. Explanation of Sheet 22.

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[7]In the year 1879 Mr. John Smith contributed a paper to our *Transactions* on the Geology of Dalry, in which he gives an account of the stratigraphy of the Lower Limestone series in the neighbourhood of Dalry, with notes on the palæontology of the different strata, but he makes no attempt to correlate them with the Renfrewshire sections.

[8]In the Summary of Progress for the year 1911 a section is given of that part of the Lower Limestone group seen at Auchenskeith Quarry, 2½ miles S.E. of Dalry. It is also stated that Mr. Carruthers believes that the bottom limestone seen in the quarry may represent the Blackbyre Limestone, and the top one the Hurlet Limestone. So far as we are aware, this is the only official statement that has yet been made regarding the correlation of the Ayrshire and Renfrewshire limestones since the revision of the former county has been begun. In the paper by Mr. Conacher and myself read to the Society last year we briefly indicated our views regarding the correlation of the two areas, it being there stated,[9] "We consider that the Nethercraigs, Howwood, and Gryffe section together afford important evidence bearing upon the correlation of the Hurlet section with those in Ayrshire. Thus it seems to us that the lower division of the Main Limestone at Broadstone, Beith, and elsewhere, with its underlying coal, is the equivalent of the Hollybush seen in the various Renfrewshire localities. The fragmental deposits lying between the lower and upper divisions of the Main Limestone of Ayrshire, as seen at Broadstone, is the representative of the Hollybush Sandstone, while the upper division of the Main Limestone, as seen at Dockra, is the equivalent of the Blackbyre Limestone, the position of this limestone being fixed over a large part of the north of Ayrshire by the capping of ashy muds with limey nodules, which we have shown is so characteristic of this horizon in the Renfrewshire sections. The Hurlet in the north of Ayrshire has dwindled to less than its thickness in the type section, and the top of the

[7] The Geology of Dalry. *Trans. Geol. Soc. of Glasgow*, vol. vi., p. 151.

[8] Summary of Progress of the Geological Survey for 1911, p. 48.

[9] The Stratigraphy of the Limestones lying immediately above the Calciferous Lavas in the Glasgow District, by Peter Macnair and Harry R. J. Conacher. *Trans. Geol. Soc. of Glasgow*, vol. xv., p. 37.

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Lower Limestone series is marked by beds of limey shale with *Posidonomya corrugata*, which have a very striking resemblance to the shales and limestones of Calderwood Glen.

I very much regret that I have not been able to obtain Mr. Conacher's valuable assistance in the writing of this paper, but he assures me that he is still at one with me regarding the above reading of the Renfrewshire and Ayrshire sequence.

III. Renfrewshire Sections.

The Hurlet District.—The lowest definite limestone horizon in the Hurlet district is that which appears at Hollybush Farm, about $1\frac{1}{4}$ miles to the west of Hurlet; it has been named the Hollybush Limestone. At this point the exposure is not extensive, and is somewhat obscured by vegetation, all that can now be seen being a bed of limey shale evidently overlying the position of the more massive limestone. The dip of the beds is towards the south, and fossils are not easily procurable. But an idea of the fauna may be obtained from the loose blocks lying about, or which have been built into the neighbouring walls. The characteristic forms are principally *Lithostrotion* and cup corals with large *Producti*, including *Productus giganteus*, *P. latissimus*, *P. punctatus*, and *P semireticulatus;* other brachiopods are *Spirifer trigonalis*, *Seminula ambigua*, and an *Athyrid*. In the shale overlying the limestone there is a bed crammed full of crushed specimens of *Rhynchonella pleurodon*. The limestone is seen to be overlain by the Hollybush Sandstone, and the strata below it, which is seen in the burn section to the west of the farm, consists of ashy muds and sandstones.

The only other exposure of the Hollybush Limestone in the district is that at the reservoir in the policies of Hawkhead, and that can only be seen when the water is low. The limestone resembles that of Hollybush, and the general aspect of the faunal association is much the same, namely, corals and large *Producti*. A number of large slabs of the limestone were pointed out to me by Mr. Hay, who assured me that they had all been taken from the quarry in the reservoir. They aver-

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aged about 2 inches in thickness, forming a bed of *Lithostrotion fasiculatum* and *Lithostrotion junceum*, through which are scattered numerous specimens of *Productus giganteus* and *P. latissimus*. An examination of another small slab of the limestone reveals a remarkably rich fauna, which, in addition to the fossils just mentioned, contains zaphrentid corals, crinoids, and various species of Polyzoa. Below the limestone is a thin band of coal and a band of dark shale full of *Rhynchonella pleurodon*, and *Productus longispinus* is exposed about sixty yards further up the stream. This is probably the same band as occurs above the limestone at Hollybush.

The Hollybush Sandstone has been recently quarried a little to the south of Hollybush Farm, and can be traced in a fairly continuous outcrop in a north-westerly direction by Low Oldbar to the dam in the Hawkhead policies. The limestone and sandstone which outcrop between Boyleston, Crosstobs, and Brownside House are probably also upon this horizon. In the centre of the Hollybush Sandstone there is a thin coal known as the Lady Ann Coal.

At a distance varying from 10 to 20 fathoms above the Hollybush Sandstone lies the Blackbyre Limestone, which is seen in the railway cutting near the farm of that name, a mile to the south-west of Hurlet. About 7 feet is exposed in the cutting, but neither the top nor the bottom of the limestone is seen. The upper part is composed of small encrinite fragments; the lower is slabby, and is almost entirely composed of small brachiopods, principally *Productus longispinus* and *Spirifer duplicicosta*. Plant remains are not uncommon.

Between the top of the Blackbyre Limestone and base of the Hurlet there occurs a somewhat variable group of strata which, because of its stratigraphical position between these two limestones, can be definitely traced over a large part of the Glasgow district. In the Hurlet neighbourhood there are but scanty exposures of this horizon. An interesting section—now, unfortunately, covered up—was laid bare during building operations on the site of the Renfrewshire Poorhouses at Old Crookston. The dip of the strata was similar to that seen at Hollybush, namely, at a low angle towards the south-east.

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Beneath the Hurlet Limestone, which varied from 2 to 3 feet in thickness, came the alum shale, only 1 or 2 inches thick at this point. Below this was an intrusion of dolerite from 10 to 15 feet thick, which was followed by thin bands of a dark entomostracan limestone with fish remains 2 inches in thickness, dark blue blaes 1 foot, and a band of grey cement limestone with rootlets, 8 inches of which was seen. The last-mentioned member of this group may be seen cropping from beneath the dolerite sill at Old Crookston Farm, where, in addition to the rootlets, it contains fish teeth, spirorbis, and entomostraca. The striking resemblance of this section to those seen at Thorntonhall has already been noticed by the officers of the Survey and by Mr. Conacher and myself, and we think that there can scarcely be any doubt that they represent a phase of the Baldernock Limestone so well developed in the Campsie district. In a future part of this paper further evidence will be adduced as to the identity of these two horizons.

The paucity of exposures of the strata lying below the Hurlet Limestones is, unfortunately, also true regarding the limestone itself. At one time it was extensively worked in Raes Wood, to the south of Hurlet House, and the Survey record its exposure at that locality in an old "ingoing eye," but since then this has also been obscured. Perhaps the best exposure is that to be seen near Arklestone, on the Glasgow and Paisley Joint Railway, where, as at Crookston, the Hurlet position has been invaded by a sill of dolerite. At this locality the limestone has a maximum thickness of 3½ feet, and is underlain by about 6 inches of alum shale, much altered by contact with the sill. Below the sill comes some 18 feet of shale, fireclay, and dark impure limestone with entomostraca, and this graduates down into green ashy muds, with a band of nodular limestone similar in every respect to that seen at Old Crookston Farm. The whole section at once recalls those at Crookston and Thorntonhall.

The strata seen in the Arkleston cutting dip towards the east, and it is interesting to note that Mr. M. Blair,[10] in his paper on the Surface Geology of Paisley, draws attention to the

[10] *Trans. Geol. Society of Glasgow*, vol. ix., p. 139.

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existence of a stratum of weathered limestone which was formerly exposed on the north embankment of the railway from the bridge over the line to the signal-box. He says that this band exhibits a richer variety and a more abundant quantity of delicate organisms than I have yet seen in any section of these deposits. There can scarcely be any doubt that the limestone referred to is the Blackbyre.

The small exposure of crinoidal limestone seen above the dolerite sill on the banks of the Cart at Blackhall, S.E. of Paisley, probably also belongs to the Hurlet horizon, while the hollow further to the west marks the outcrop of the Blackbyre; this is confirmed by the blocks of limestone found in the surrounding walls and old buildings, which are typically Blackbyre in their character.

The strata between the Hurlet and the Blackhall Limestones consist of shales and a group of ironstones known as the Househill Clay bands, which immediately underlie the Blackhall Limestone. This limestone can be examined in the old quarry at Jenny's Well, near Blackhall, Paisley, where it is seen to be in several beds; the upper part, which is about 24 inches thick, is crinoidal and contains marine shells, while the lower part, which consists of alternations of shale and limestone over 4 feet in thickness, is entirely composed of ostracoda and fish remains, the ordinary marine fossils being absent. These characteristic features of the Blackhall Limestone have been found to hold good over a large area in the Glasgow district. The only other locality where the Blackhall Limestone can be seen in the Hurlet district is on the banks of the Levern Water, east of Hurlet, but neither the top nor the bottom of the limestone is shown at this point, the exposure being confined to the entomostracan limestone and its accompanying shales.

Immediately on the top of the Blackhall Limestone there occurs a bed of shale which in the Campsie district and at Thorntonhall, East Kilbride, is exceedingly fossiliferous, and has yielded a somewhat striking faunal association. It was first described from the South Hill of Campsie by the late Dr. John Young, where it lies immediately above the Blackhall Limestone. Subsequently Mr. James Neilson found it in the

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Thorntonhall quarries, where the stratigraphical position of the limestones has recently been a matter of considerable dispute. Unfortunately, this shale band is not exposed either at Blackhall or the Levern Water, the nearest point where it is to be seen being in the Gryffe Water, at the Bridge of Weir. This section will presently be described when the characteristic features of this horizon will be dealt with in more detail.

The strata between the Backhall Limestone and the Main Hosie Limestone consist for the most part of shales in the lower division and sandstones in the upper, the latter being known as the Hosie Sandstones. The outcrop of massive encrinital limestone which crops out in the Levern Water just below the Cross Arthurlie Street Bridge has been identified by the Survey as the Main Hosie Limestone. If this is correct, it is the only exposure of the limestone in this district, though its presence is certified by numerous bores.

The Lillies coal and oil shale, which lies between the Main Hosie and Top Hosie, is not, so far as we are aware, exposed in the Hurlet district, but it is met with in numerous bores. The nearest exposure is at Lochar Mill, Bridge of Weir, which will presently be described. No exposure of the Top Hosie can be seen in the district.

The Calderwood Cement, with the *Posidonomya corrugata* horizon, the Johnstone Clay Band, and the Upper Marine Band which lies some fathoms above the Johnstone Clay Band, though proved by bores to be present, are nowhere exposed at the surface in the Hurlet area. But all of these horizons have been found in the ironstone pit sunk by Messrs. Bairds at Cockerhill. Fragments of the Calderwood Cement, with *Posidonomya corrugata*, fish teeth, scales, and plant remains, can still be picked up on the bing. The ironstone found in the pit is from the Johnstone Clay Band horizon, and fragments of the top marine band, with its overlying Lingula shale, can also be picked up on the bing.

Such, then is a brief summary of the principal horizons that have been identified in the type section of the Hurlet district. They are given in tabular form in descending order, along with their correlatives in North Ayrshire.

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TABLE OF PRINCIPAL HORIZONS IN THE HURLET DISTRICT AND THEIR EQUIVALENTS IN NORTH AYRSHIRE.

HURLET DISTRICT.	NORTH AYRSHIRE.
Lingula Shale and Marine Bed,	Lingula Shale and Marine Band.
Johnstone C. B. Ironstone,	Main Clayband Ironstone.
Top Hosie Limestone (Calderwood Cement),*	Fourth Limestone above Dockra.*
Lillies Coal and Ironstone,	
Main Hosie Limestone,	Third Limestone above Dockra Limestone.
Hosie Sandstone,	
Blackhall Limestone,	Second Limestone above Dockra Limestone.
Househill Ironstones,	
Hurlet Limestone,	First Limestone above Dockra Limestone.
Alum Shale,	
Hurlet Coal,	
Baldernock Limestone,	Limey Nodules above Dockra Limestone.
Blackbyre Limestone,	Dockra Limestone.
Hollybush Sandstone,	Divisional Shales.
Hollybush Limestone,	Broadstone Limestone.

* *Posidonomya corrugata* abundant at this position.

NETHERCRAIGS.—The scarcity of sections in the Hurlet district is somewhat made up for by the remarkably fine exposure of the Hollybush, Blackbyre, and Hurlet Limestones, and their accompanying strata, seen at Nethercraigs, 3½ miles to the west of Hurlet. At this locality the strata have been thrown into a basin, and a fairly continuous succession can be observed from a considerable distance below the Hollybush to the top of the Hurlet Limestone. The limestones are bounded to the south by the fault which throws them against the Calciferous lavas. The outcrops of the Hollybush, Blackbyre, and Hurlet Limestones appear in three more or less continuous rings, with the last-mentioned limestone in the centre. The whole three limestones have been quarried at different points, and are exposed in stream sections. There can be no doubt as to the identity of the respective limestones with those of the Hurlet district, as their stratigraphical and palæontological features are exactly similar. Thus the Hollybush, which is exposed in a quarry on the east side of the basin and in the stream section near the boundary fault on the west, is characterised by the

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same fauna as that seen at Hollybush and Hawkhead. In the former locality, which probably represents the lower part of the band, it is a massive limestone with large *Producti* and *Lithostrotion*, while in the latter it is a greenish limestone tinted with the ashy muds and crammed full of *Rhynchonella pleurodon* and *Productus longispinus*. The Hollybush and Blackbyre Limestones are separated by the Hollybush Sandstone, which appears on the hillside on the east of the basin, and in the stream section in the west.

The Blackbyre Limestone presents all the features seen at the type locality, is 14 feet in thickness, and is largely composed of small brachiopods and crinoids, with an occasional cup coral and bands and nests of *Chætites tumidus*. It is interesting to note that towards the top the limestone assumes the peculiar finely crystalline character, with minute concretions of sphærosiderite, which we shall presently see is characteristic of the top of the Blackbyre Limestone over a large area.

It is here considered necessary to describe in some detail the nature of the sediments which lie between the top of the Blackbyre Limestone and the bottom of the Hurlet, and to compare them with the strata lying upon this horizon in the Hurlet district. In the joint paper by Mr. Conacher and myself we noted the existence of an unconformity at the top of the Blackbyre Limestone, the two beds being separated by a thin layer of ashy fireclay. In the same paper we pointed out that this apparent break at the top of the Blackbyre Limestone could be traced to the north of Glasgow, where the limestone was succeeded by a sandy limestone, which in turn was overlaid by the Baldernock (Entomostracan) Limestone, the Hurlet coal, alum shale, and Hurlet lime. At Nethercraigs the sandstone above the Blackbyre Limestone is followed by green and purplish ashy muds, with nodules of limestone, which in the western burn is seen to run into a regular band with rootlets, and which at once suggests the similar band observed at Crookston, in the Arkleston cutting, and at Thorntonhall, East Kilbride. In fact, we consider that all the evidence goes to show that this band is the equivalent to the south of Glasgow of the Baldernock Limestone to the north. Above the nodular limestones come more ashy muds, which include a hard, limey.

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brecciated band seen both in the burn section and in the quarry. The strata immediately below the Hurlet Limestone is grassed over, and cannot be seen. The position may be occupied by representatives of the alum shale. The most surprising phenomenon of this section is that the Hurlet Limestone, which is only from 2 to 3 feet in thickness, has, at Nethercraigs, risen by the addition of limey shales to over 30 feet.

Howwood.—We regard the Howwood section seen in the burn at Meikle Corseford as being one of the most important links not only between the limestones of Renfrewshire and Ayrshire, but also as affording hints as to the possible correlation of the limestones of the West of Scotland with those of the east. Howwood lies about 8 miles to the west of Hurlet, and a similar distance to the north of Beith, and is therefore about midway between the two areas, which it is the object of this paper to correlate. The Hurlet Limestone has been quarried at various points along the outcrop extending from the village of Howwood in a north-easterly direction for over a mile. At this point the Hurlet Limestone presents all the features of the Nethercraigs section both as regards its thickness, lithological characters, and fossils. At the base there is a hard crinoidal limestone, 6 feet in thickness, which is overlaid by 30 feet of limey fossiliferous blaes containing irregular bands of limestone full of large crinoid stems and fragments of fingers, with *Productus longispinus* and Polyzoa, the former occasionally to be found matted together in great numbers. In the various quarry sections the limestones are seen to graduate downwards into the alum shales, with crushed brachiopods and lamellibranchs beneath, which comes about 16 inches of pyritous coal underlain by ashy fireclay.

In the burn section at Meikle Corseford the succession has been somewhat obscured by the débris from the quarrying operations, and complicated by small faulting, but notwithstanding this, we think the succession is quite clear from the Hurlet down to the Hollybush Limestone. Immediately below the Hurlet Limestone comes the alum shale position, which has yielded a somewhat remarkable faunal association, and which to us seems to be of considerable significance. The fossils, which are exceedingly numerous, though badly crushed, are principally

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brachiopods and lamellibranchs. Of the former, the most common are *Schizophoria resupinata* and *Productus semireticulatus*. The most abundant lamellibranchs are *Sanguinolites abdenensis*, *Streblopteria ornata*, *Actinopteria persulcatus*, and *Myalina Verneuili*. Now, it is interesting to note that these four lamellibranchs occur in association in exactly the same stratigraphical horizon in the Campsie district and at Corrieburn. They were first noticed in the débris at the mine mouth at Glorat, where they occur in a somewhat peculiar and easily recognised shale, and though they cannot be seen *in situ*, yet their position in the shale below the Hurlet Limestone seems to me to be unquestionable. This, however, is placed beyond all possible doubt by an examination of the section of the Hurlet beds seen at Corrieburn. Here the peculiar shale occurs immediately below the Hurlet Limestone, and between it and the underlying Hurlet coal and the four species of lamellibranchs just mentioned are the characteristic fossils. The other fossils in association with these at Howwood include *Naidites crassa* and *Edmondia sulcata*. Spines and plates of *Archæocidaris Urei* are numerous, and at times appear to form a regular bed in the shale. As a rule, the alum shale position may be considered to be comparatively unfossiliferous, though in the Campsie district the characteristic fossils are *Sanguinolites costellatus*, *Bellerophon Urei*, and *Productus longispinus*. This faunal association appears below the lamellibranch bed at Corrieburn. The stratigraphical value of these fossils will be discussed in a future part of this paper.

Returning to the section at Howwood we find this fossiliferous shale to be underlaid by the Hurlet Coal, which passes down into green and purplish ashy muds and fireclays, with irregular strings of limey nodules, the lithological aspect of the whole group at once recalling that described as occurring at Nethercraigs between the Hurlet and Blackbyre Limestones.

At this point there is a fault which again brings down the base of the Hurlet Limestone into the stream section, and from this up the section appears to be an unbroken one. The alum shale and green ashy muds with limey nodules are repeated below a small waterfall formed by the irregular top of the Blackbyre Limestone, which is seen dipping at a high angle down stream.

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The limestone, which is finely crystallised, is tinged with irregular blotches of greenish colour, derived from the overlying ashy muds, and often presents a sort of brecciated appearance. The marine origin of the limestones is made clear by the abundance of crinoid stems, Producti, and other brachiopods, the most abundant being *Streptorhynchus crenistria*, many of the beds being so crowded with specimens as to appear to be entirely made up of them, resembling the well-known occurrence of this species at Hillhead, Gatend, Cunningham Baidland, and Auchenskeith. Nests of *Lithostrotion Portlocki* occur in association with *Streptorhynchus*. About 18 inches from the top there is a band of *Lithostrotion fasciculatum*, and other bands of the same coral occur further down. The exposed part of the limestone must be over 12 or 13 feet thick, but the base is not seen. It is much interbedded with shaly and ashy partings. Proceeding up the stream a bed of sandstone with ashy muds on the horizon of the Hollybush Sandstone is passed, and this is followed by calcareous shales containing *P. giganteus*, *P. latissimus P. semireticulatus*, and *Lithostrotion fasciculatum*. The Producti are packed together as closely as they can go in a matrix of calcareous shale. There can be no doubt that we have here the representative of the Hollybush Limestone of the Paisley and Glasgow districts. The remaining part of the section is somewhat obscure, and the exact relationship of the limestone to the lavas cannot be seen. The Hurlet Limestone has been worked further up the hillside near the edge of the wood, where it is topped by shales and ironstones.

Gryffe Water and Locharmills.—Undoubtedly one of the finest sections of the Lower Carboniferous Limestone series to be seen in the West of Scotland is that on the Gryffe Water between the Bridge of Weir and Crosslee. The section begins below Houstounhead, where the basal ashy muds and conglomerates pass upwards into ashy fireclay with rootlets, irregular coal, and greenish sandstone. Above this comes a group of calcareous shales with limey nodules, passing at times into a massive limestone. A fault brings the limestone in at the ford, where the palæontological features can be examined in detail, and these at once reveal it to be the Hollybush Limestone of the former sections. The giganteid Producti form a

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regular bed, and are matted together in a similar way to that seen in the Howwood section, the species being the same, namely, *Productus giganteus*. *P. latissimus*, and *P. semireticulatus*. Branching and solitary corals appear in a regular band above, with which are associated beds almost entirely composed of crushed specimens of *Rhynchonella pleurodon*. From the ford to the old workings there is a gap. But at the latter locality the top of the Blackbyre is seen at the level of the Gryffe Water. Here it presents exactly the same aspect as at Howwood, with the exception that *Streptorhynchus crenistria* appears to be absent, the principal fossils in the fine, white, crystalline limestone being cup corals and crinoid remains. The limestone is interleaved with green ashy muds, as at Howwood.

The strata from the top of the Blackbyre to the Hurlet is obscured by the débris from the old quarry workings, but bores put down in the locality show the alum shale to vary from 1 to 2 feet in thickness, while the coal was 2 feet 6 inches thick. This was separated from the Blackbyre Limestone by 5 feet of fireclay, which may correspond to some extent with the ashy muds seen at Nethercraigs and Howwood.

Further down stream the Hurlet Limestone is thrown by a fault to the level of the water, and brought into contact with the top of the Blackbyre Limestone, from which point there is an ascending section to the bridge at Crosslee. The Hurlet Limestone is succeeded by shales and ironstones, with a thin coal above, which comes the Blackhall Limestone, presenting a somewhat different character from the type section at Blackhall. The upper part, which is 18 inches thick and crinoidal, and is similar to that seen at Blackhall, the lower part from which undoubted marine forms appear to be absent, the only organisms present being ostracods and fish remains of an estuarine type, has received an interesting modification, inasmuch as that it contains 12 inches of fireclay, with large stigmarian roots preserved in ironstone. This is underlaid by entomostracan shale and limestone of a similar character to that at Blackhall. On the top of the crinoidal limestone there is a highly fossiliferous shale, which, as it occupies the same position above the limestone as that seen in the Campsie district and at Thorntonhall, East Kilbride, is of great interest, as in these two localities it

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has been shown to have a peculiar faunal association. We have not yet been able to find any of the more characteristic fossils of this horizon, but some of the commoner forms, such as *Nautilus subsulcatus*, are identical. The Hosie Limestones are exposed on the left bank of the Gryffe near Crosslee Bridge, and the *Posidonomya corrugata* horizon at Locharmills, east of the Bridge of Weir.

Glenlora and Roebank Glen.—In the former of these two sections we are close to the Ayrshire boundary line, while in the latter we are actually upon it. Glenlora is situated about 1½ miles to the west of Lochwinnoch. At the point where the road crosses the stream the limestones are seen to pass down into ashy muds. Further down stream the creamy top of the Dockra Limestone is exposed. This is succeeded by the limestones lying between the Dockra Limestone and the Main Clay Band Ironstone, but the section is not a very clear one. Roebank Glen is situated on the other side of the valley, about 1 mile north of Beith. There is a very clear section showing the calcareous shale, No. 7 in table on page 25, resting upon the ashy muds, and passing upwards into the Broadstone Limestone. The Divisional Shales are present with the 10-inch impure coal, but the limestones above appear to be cut out by a fault.

Auchenback.—Crossing from the Howwood and Lochwinnoch gap to that of Barrhead and Lugton, we find between the two latter localities a number of exceedingly interesting isolated exposures whose exact stratigraphical position is difficult to fix, as their field relationships are somewhat obscure. The nearest of these to the Hurlet district is that exposed in the Auchenback railway cutting, about 1½ miles to the south-east of Barrhead. At this point the Cowglen Limestone and overlying Barrhead Grits have been thrown by the boundary fault against a 13-foot band of limestone, which in the upper half has several partings of limey blaes, and in the lower is a post of good limestone. The limestone contains several bands of *Lithostrotion junceum* and cup corals. Small brachiopods are also numerous, including *Productus*, *Spirifer*, and *Streptorhynchus*. The limestone passes down into volcanic muds and ashes resting upon the lavas. In "The Geology of the Glasgow

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District" the officers of the Survey have, we rightly think, correlated this bed with the Main Post of Thorntonhall, which they regard as the equivalent of the Blackbyre, as it exhibits all the lithological and palæontological characteristics of that limestone.

LEVERN WATER, NEILSTON.—Another exceedingly interesting, though, unfortunately, limited, outcrop of limestone is exposed in the bed of the Levern Water at Levernbank, a little to the north-east of Neilston railway station. The top of the limestone appears to be cut off by a fault which brings in a series of thin-bedded sandstones. The limestone, of which a considerable thickness is seen in the bed of the Levern, has a fine-grained top, and contains several bands of *Lithostrotion* and cup corals. The most striking feature of this exposure, however, is the great abundance of large *Productus giganteus*, which, we think, links it with the limestone about to be described seen about 3 miles to the south in the railway cutting at Netherton, and also with that seen in the quarries at Lugton. The strata is much broken and faulted, but the limestone appears to pass downwards into green and purplish ashy muds, as at Auchenback.

RAILWAY CUTTING, UPLAWMOOR, AND DUNIFLATS BURN.—The next link in proceeding towards the Ayrshire border is exposed in a cutting of the Lanarkshire and Ayrshire Railway a little beyond Uplawmoor station. Here the limestone, which rests upon volcanic ash beds, is lithologically and palæontologically identical with that seen in the last section, the characteristic fine-grained top being covered with a thin layer of green ashy mud, which may be seen by a little digging into the cutting just above the top of the limestone. The following is the section in descending order:—

	Feet.	Inches.
Shales with a band of C.B. Ironstone, - - -	2	6
Green ashy mud, - - - - - - - - - -	2	0
Fine grained purply Limestone with irregular hummocky top, - - - - - - - - - -	2	0
Shaley Limestone with *Productus giganteus* and *Spirifer duplicicosta*, - - - - - - - - - -	3	6
Dark Limestone, - - - - - - - - - -	1	6
Volcanic ash beds, - - - - - - - - -		—

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A fault crosses the railway with downthrow to the south, bringing the Johnstone Clay Band Ironstone and the limestones immediately underlying it against the lower limestones just described. The section exposed in the railway cutting is as follows:—

	Feet.	Inches.
Johnstone Clay Band Ironstone,	1	0
Shales,	10	0
Calcareous Shales (Calderwood cement),	7	0
Shale with C.B. Ironstones,	3	0
Sandstone,	1	0
Fireclay,	5	0
Fakes,	1	0
Encrinital Limestone,		—

Exactly the same succession is exposed in the Duniflats Burn, which here marks the boundary line between Renfrewshire and Ayrshire. The railway here crosses a line of fault, to the east of which, in the bed of the burn, the irregular top of the lower limestone, with its overlying bed of greenish ashy mud and shales with ironstones, are exposed. Passing below the railway and crossing the fault, the limestone and calcareous shales upon the horizon of the Top Hosie and Calderwood Cement are seen. The fossils in the calcareous shales are principally a *Pecten*, *Discina nitida*, and *Productus longispinus*. We are here upon the position of the *Posidonomya corrugata* horizon, but as yet we have only been able to find a few doubtful specimens of that fossil. Further search, however, may yet reveal it in a better state of preservation, along with its characteristic associations. The calcareous shales in the above group are seen to pass at times into a calmy limestone with shells, crinoid stems, and large ostracods, a bed which has been identified on this horizon over a large part of North Ayrshire.

Above this comes about 10 feet of shales and the Johnstone Clay Band Ironstone. These are succeeded further down stream by a series of sandstones and shales. About 30 feet above the Johnstone Clay Band Ironstone there is exposed in the bed of the burn a shale full of *Lingula squamiformis*, and below is a band containing marine fossils, which represents the highest marine band in the Lower Coal and Ironstone series.

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In the Craig Collection in Kelvingrove Museum there are the following five species, labelled as from the fossiliferous shales and coarse limestone, 3 fathoms above main clay ironstone, Netherton Pit:—*Productus longispinus*, *Aviculopecten knockonniensis*, *Cypricardia sp.*, *Loxonema Lefebvrei*, and *Macrocheilus acutus*.

IV. Ayrshire Sections.

Lugton Quarries and Lugton Water.—Passing now to a consideration of the Ayrshire sections, we begin with those exposed in the Lugton Water and neighbouring quarries near Lugton junction. The section is taken in ascending order as exposed along the eastern bank of the Lugton Water. At the base lie the volcanic ash beds which are seen to pass upwards into fossiliferous calcareous shales, with a band of *Naidites crassa;* above them comes a green limestone with *Lonsdaleia* and *Productus giganteus*. We shall see that a similar band lies above the basal ash beds in Paduff Burn, and we consider them to be upon the same horizon. The green limestone is followed by beds of fireclay, coal, and shale, the equivalents of the Divisional Shales of the Broadstone Quarries, Beith. On the top of the latter is the 30 feet of limestone which has been so extensively quarried in this neighbourhood. The limestone is largely built up of the broken stems of crinoids and brachiopods, principally belonging to the genera *Productus* and *Spirifer*, and there are three or four bands of *Lithostrotion junceum*. The characteristic fine-grained top of the limestone can be seen crossing the bed of the stream a little above the dolerite dyke. In some places it shows a brecciated structure, while at others the top layers of the hummocky surface presents a finely banded agate-like structure, due to the arrangement of the sphærosiderite concretions in definite layers. We have found this structure on the same position at Howrat and other localities along the west side of the basin, which is an additional point in helping to identify this well-marked horizon.

Long ago Mr. R. Craig identified the limestone wrought in the Lugton Quarries as the equivalent of the Upper series in the

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Beith Quarries, this group being then wrought at Trearne, Hillhead of Broadstone, and Dockra. The first two of these quarries have long been filled up, and Dockra is now the only one where the group can be seen in the neighbourhood of Beith. The calcareous shales and green limestone lying immediately above the volcanic ashes in this section we consider to be the equivalents of Mr. Craig's Lower series, which, with the overlying Divisional Shales, are so well developed in the Broadstone Quarries at Beith. These two bands lie at the base of the Limestone series in this district, and can be traced, with certain modifications, right round the basin. We shall retain the name Broadstone Limestone for the lower group, and Dockra Limestone for the upper group, in describing their outcrop round the North Ayrshire basin. In a future part of this paper we hope to be able to show that they are respectively the equivalents of the Hollybush and Blackbyre Limestones of the Renfrewshire sections.

Between the dolerite dyke which crosses the Lugton and the railway viaduct a bed of limestone and calcareous shales crop out, and another and still higher band is seen further down the stream. We shall see that between the top of the Dockra Limestone and the Johnstone Clay Band Ironstone a number of thin limestones crop out all round the basin. These will be considered in more detail when we come to the Gurdy Cutting and Paduff Glen sections, where they are well exposed, and where their relationships may best be studied. In the meantime we may simply state that the lowest of these in the Lugton section is probably the equivalent of the Blackhall Limestone in the Renfrewshire sections, while the upper is the same as the Main Hosie of that district. To the east of the Lugton Water the Clay Band Ironstone was worked in a pit which is now filled up. It was also mined on Waterland Farm in a series of "ingaun ees." In connection with it there was a thin layer containing fine specimens of "Cone in Cone" or "Maggie band." The relationship of the Clay Band Ironstone to the underlying limestones is the same as that seen in the Duniflats Burn.

Hessilhead.—The next section which falls to be considered is situated about 1½ miles to the west of Lugton junction, in the

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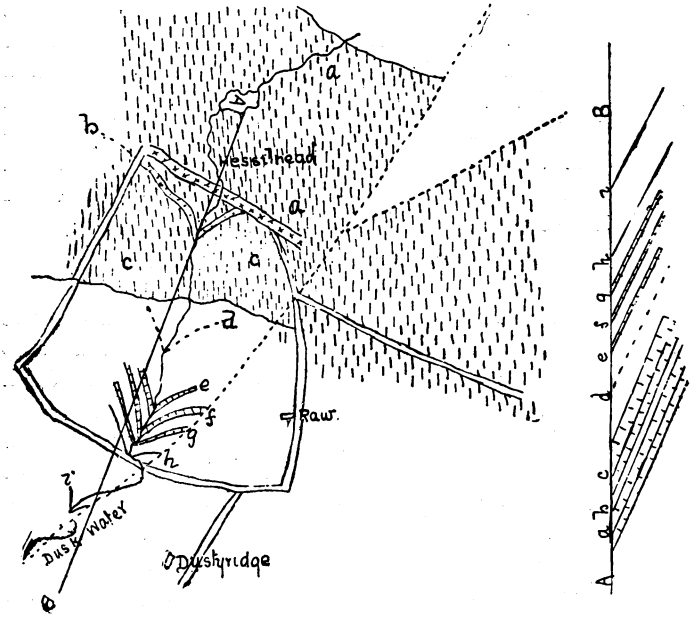
bed of the Dusk Water, between Hessilhead and Dustyridge. A little below the bridge at Hessilhead Mill the Broadstone Limestone, which here dips down stream, is seen to pass upwards into ashy muds and shales, which are succeeded by the Dockra Limestone. This is followed by a considerable thickness of black shale, followed by two bands of limestone, probably the equivalent of the Blackhall and Main Hosie limestones respec-



PLAN AND SECTION ALONG THE LINE A B. DUSK WATER HESSILHEAD.

a, Broadstone Limestone; *b*, Divisional Shales; *c*, Dockra Limestone; *d*, Position of Hurlet not seen in stream; *e*, Blackhall Limestone; *f*, Hosie Limestone; *g*, Calderwood Cement and *Posidonomya corrugata* Shales; *h*, Main Clayband Ironstone; *i*, Marine Band.

tively; more black shales supervene, upon which the Calderwood Cement Band, or Top Hosie, with its accompanying *Posidonomya corrugata* beds are seen to rest. Further down stream, at the bridge where the road to Beith crosses,[11] the Clay Band Ironstone is exposed on the right bank, and the *Posidonomya corrugata* beds and Calderwood Cement on the left.

[11] The Laverockhall locality of Mr. Craig's papers.

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At this point the strata dip at high angles to the north-west, as we are in close proximity to the important line of fault which runs from Ardrossan north-eastwards into the Renfrewshire coalfield at Neilston. At one point this fault has the effect of bringing down the lower portion of the Upper Coal Measures against the volcanics beneath the Lower Limestones. Still further down stream, near Dustyridge, the uppermost marine zone and *Lingula* shales are found lying against the fault. It ought not to be forgotten that the position of this band, with its great variety of marine organisms, was pointed out in the year 1882 by Mr. Craig, who, after describing the Clay Band Ironstone, says, "From 1 to 3 fathoms above this is a very rich fossiliferous band, varying in thickness from a calcareous shale of a few inches to a coarse limestone of 20 inches. It lies above a thin rib of ironstone and coal, immediately above which *Lingula*, scales of *Rhizodus*, and land plants are found, with in some places a profusion of brachiopods, lamellibranchs, gasteropods, and cephalopods." At Crookhill, about three-quarters of a mile further to the west the same bed was found in open section, and its fossils were carefully collected and tabulated by Mr. Craig in a separate column of his paper on this series.[12] He also notes that at Crookhill the spines of *Archæocidaris Urei* were abundant in one part of the shale, and both here and elsewhere crinoid stems are found, but not very plentiful. This bed was also struck when sinking a pit at Glencart, Dalry, from which locality Mr. Craig records a specimen of *Goniatites Listeri*.

Broadstone and Dockra Quarries.—We come now to the well-known sections exhibited in the various quarries in the neighbourhood of Beith. It is unnecessary that we should describe all the exposures, so we confine ourselves to the inferior beds and Divisional Shales as seen in the Broadstone Quarry and the superior beds as seen in the Dockra Quarry.

Broadstone Quarry, about a mile to the south-east of Beith, shows a complete section of the Broadstone Limestone and the Divisional Shales. Even the beds below the limestone, including the fossiliferous shale and coal, were exposed some years ago, but they have unfortunately been again covered up by

[12] *Trans. Geol. Soc. of Glasgow*, vol. vii., p. 86.

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quarrying operations. The following section, copied from Mr. Craig's paper, gives the succession and thickness of the various beds seen in descending order:—

TABLE OF STRATA SEEN IN BROADSTONE QUARRY.

		Feet.	Inches.
Divisional Shales.	22. Calcareous shales with bands of limestone,	20	—
	21. Bituminous shale with band of clay ironstone,	2	—
	20. Clay ash (unfossiliferous),	5	—
	19. Bituminous shale,	1	—
	18. Clay ash (unfossiliferous),	2	—
	17. Arenaceous shale with remains of land plants,	4	—
	16. Impure limestone band with marine fauna,	—	10
	15. Shale of mixed character with marine fauna,	—	9
	14. Coal,	—	9
	13. Shale of mixed character with marine fauna,	4	—
Broadstone Limestone.	12. White limestone with marine fauna,	7	6
	11. Blue limestone with marine fauna,	5	—
	10. Coral shale band with marine fauna,	1	11
	9. *Lithodendron* limestone with marine fauna,	2	—
	8. Main post limestone with marine fauna,	4	6
	7. Argillaceous shale with marine fauna,	3	—
	6. Coal,	1	4
	5. Clay shale full of the remains of land plants,	2	—
	4. Layer of coal,	—	4
	3. Clay ash from 2 to 30 feet,	—	—
	2. Red shaley sandstone and clay,	11	—
	1. Volcanic ash and lavas,	—	—

The argillaceous shale, No. 7, which rests upon the coal is almost entirely built up of crushed shells, and furnished Mr. Craig with 50 per cent. of the genera which he records from the inferior limestone beds of the Beith district, and which he includes in his list of the first appearance of certain fossils in the Carboniferous strata around Beith and Dalry. This rich shale is probably on the same horizon as that seen at the bottom of the Lugton section, and also at the bottom of the Paduff Glen section about to be described. The band of *Naidites crassa* seen on this horizon at Lugton also makes its appearance at Broadstone midway, at Lyonshields, and further to the west at Roughwood. The main post, No. 8, is a massive crinoidal limestone containing practically the same fauna as that found in the underlying shale. It passes upwards into a coral band

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from 2 to 3 feet thick almost entirely composed of one mass of *Lithostrotion fasciculatum* and *L. junceum*, with which is associated *Productus giganteus*. This bed at once reminds us of the Hollybush Limestone as it is developed in the Lanarkshire and Renfrewshire sections. On the top of the *Lithostrotion* bed is another coral band, No. 10, which, unlike the underlying bed, consists almost entirely of such genera as *Calophyllum*, *Zaphrentis*, *Campophyllum*, *Diphyphyllum*, *Clisiophyllum*, *Dibunophyllum*, *Aulophyllum*, and others. The shale in which they occur varies in thickness from 1 to 2 feet; it is partly calcareous and partly argillaceous, the corals being most abundant in the latter, from which they could be gathered by the bushel when the quarry was being worked. Resting upon the coral band are two posts of limestone, the lower known as the blue post and the upper as the white post. These limestones are impure and flaggy, and have a very irregular development, their thicknesses varying considerably within very short distances. Like the underlying limestones, they are highly fossiliferous *Terebratula hastata* being one of the most abundant fossils.

It is in the Broadstone Quarry that we see the most extensive development of the Divisional Shales, for in that section they reach a thickness of close on 40 feet. These shales have already been noted as occurring at Lugton, where they have a thickness of 21 feet, and at Hessilhead, where they are about the same thickness, and we shall see that they are found in a more or less modified condition right round the whole basin.

Resting on the top of the Broadstone Limestone is a bed of calcareous shale, No. 13, in which *Naidites crassa* reappears. This species, which first appears in a well-defined band in the shale underlying the Broadstone Limestone, does not occur in the limestone itself, but reappears in this shale. Above this is a 9-inch coal, which is succeeded by an argillaceous shale 9 inches thick, which is rich in fish remains having a general resemblance to those found in No. 7 above the bottom coal. Compared with the underlying limestone, this shale is poor in molluscan remains, the most common shells being Lingula and Crania; these are found in the shale below the lower coal, but are practically absent in the intervening strata. Above

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this is a band of impure limestone, No. 16, followed by arenaceous shales with plant remains, unfossiliferous ashy clays, in the midst of which is a band of bituminous shale, the whole being capped with calcareous shales and thin bands of limestone.

The limestones of the upper series are now best seen in Dockra Quarry, about half a mile to the south of the Broadstone Quarry. At their maximum development they have a thickness of close on 40 feet. They consist of beds of limestone varying from 1 up to 4 feet thick intercalated with thin bands of shale, these being very characteristic of the series. Both the limestones and the shales are often found to have a greenish tinge, due to the presence of ashy material derived from the underlying volcanic rocks, and in this respect they resemble the Blackbyre of Howwood and the Gryffe Water. Besides Dockra, the group was formerly wrought at Trearne, Hillhead of Broadstone, Gatend, Oldmill, and North Biggart, Beith. They were also wrought at many localities round the basin, including Paduff Glen, Howrat, Cunningham Baidland, Auchenskeoch, and Auchenmade. Palæontologically the Dockra Limestone is found to be largely composed of crinoid stems and brachiopods, though on the western side of the basin, as in Paduff Glen, there is a distinct departure from the Dockra or Trearne type, crinoid stems being rare, and the limestone, which is fine-grained, is comparatively unfossiliferous. Near the base of the limestone at Hillhead and Dockra there is a coral band, which includes the following genera, amongst others:—*Lithostrotion*, *Amplexus*, *Campophyllum*, and *Zaphrentis*. Still higher is another coral band, and above it near the top of the series a bed of white limestone often 10 feet in thickness. This bed is exceedingly rich in crinoids and brachiopods, sometimes the one predominating and sometimes the other. Among the more common shells are *Productus semirecticulatus*, *P. scabriculus*, *P. spinulosus*, and *Spirifer duplicicosta*. They are occasionally found with hollow interiors, which are filled with calcite, fluor, and millerite.

The foot of fine-grained limestone, generally free from crinoids and other fossils, with the exception of ostracods, which caps the limestone at Duniflats and Lugton, presents a somewhat different appearance at Dockra, approaching more closely to the

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top of the Blackbyre as seen at Howwood and the Gryffe Water. But the general appearance and the presence of the greenish ashy bed above can scarcely leave any doubt as to their identity. At Dockra this top band contains more crinoids and other marine fossils than at Lugton or Duniflats. But, like them, it is seen to be penetrated by stigmarian rootlets and strings of ashy mud derived from the overlying layer.

It seems quite clear that after the deposition of the Dockra Limestone the whole of this part of western Scotland was upheaved above sea-level, and that an estuarine condition of things began to prevail. It was formerly considered that the green ashy mud was of true volcanic origin, but we think that it is more likely to represent a rewash of ashy material from the land surface deposited over the estuaries and lagoons bordering upon the seashore. Upon this land surface vegetation soon began to establish itself. The roots of the trees penetrating through the ashy mud into the soft limestone carried down strings of the ashy mud into the limestone, the two being mixed together whilst they were yet in a soft condition.

The strata overlying the Dockra Limestone have been exposed in the old tram line to the south of the quarry, of which the section is as follows:—

	Feet.	Inches.
Shale resting upon the green ashy muds, - - -	11	0
Limestone, - - - - - - -	2	10
Calcareous Shale, - - - - - - - -	2	0

At this point a fault intervenes which brings in a group of sandstones belonging to a higher horizon. These beds, lying immediately on the Dockra Limestone, we consider to be on the same horizon as the Hurlet series of Renfrewshire and the Glasgow district, the shale resting upon the green ashy muds being the equivalent of the strata that lie between the Blackbyre and the Hurlet Limestones, and the limestone seen in the section being the representative of the Hurlet Limestone of Renfrewshire. The stratigraphical and palæontological evidence bearing upon this correlation will be discussed in the succeeding part of this paper. It is from the shale below the limestone that Mr. Craig records the first appearance of *Sanguinolites costellatus* in the Ayrshire rocks, one of the common fossils of the alum shale.

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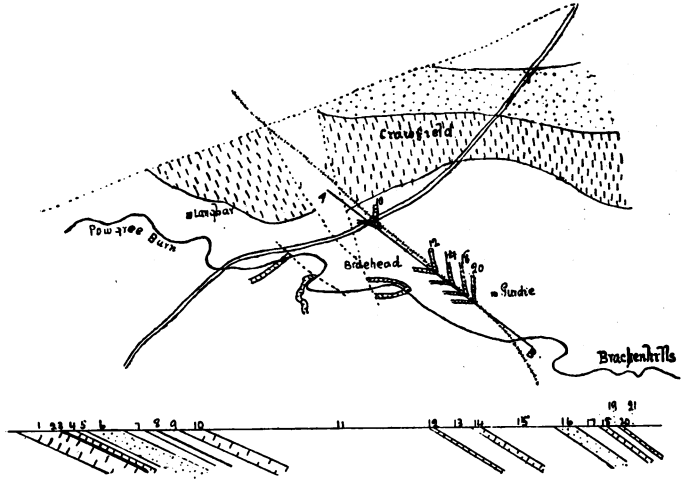
GURDIE RAILWAY CUTTING.—This, along with the following section, is perhaps the most complete in the Ayrshire basin, as they include, with some minor gaps, the whole of the Lower Limestone series from the Broadstone Limestone to the beds lying above the Calderwood Cement. The lower part of this section is seen in Crawfield Quarry, three-quarters of a mile to the west of Glengarnock station, while the upper part is exposed in a cutting of the Lanarkshire and Ayrshire Railway, and extends from a point where the railway crosses the Beith and Kilbirnie road to near Brackenhills station. The following



PLAN AND SECTION ALONG LINE A B., LANARKSHIRE AND AYRSHIRE RAILWAY CUTTING, GURDIE, GLENGARNOCK.

Numbering same as on Table, page 229.

table shows the different strata exposed either in the quarry or in the railway cutting:—

TABLE OF STRATA AT CRAWFIELD QUARRY AND GURDIE CUTTING.

	Feet.	Inches.
21. Shales with P. corrugata,	0	6
20. Calderwood cement,	0	9
19. Shales with P. corrugata,	1	3
18. Limestone (Hosie),	2	7
17. Shale,	7	0
16. Sandstone with plants,	4	3

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	Feet.	Inches
15. Shale with ironstone balls,	20	0
14. Limestone (Blackhall),	2	4
13. Shale,	28	0
12. Limestone (Hurlet),	1	2
11. Shales and ironstones,	60	0
10. Limestone (Dockra),	6	0
9. Shale and ironstone,	8	0
8. Coal,	0	6
7. Fireclay,	1	3
6. Sandstone,	8	0
5. Flags and shale,	2	6
4. Limestone,	1	3
3. Coal,	0	9
2. Shale,	0	3
1. Limestone (Broadstone),	12	0

The Broadstone Limestone, No. 1 in the foregoing table, is exhibited in the quarry sections at Crawfield Farm; it contains a well-marked band of cup corals which may be the same as No. 10 in the Broadstone Quarry. The identification of this with the Broadstone Limestone lies principally in its stratigraphical relationships, as there can scarcely be any doubt that the succeeding strata are the Divisional Shales of Broadstone. The shale No. 2, which lies between the basal limestone and the coal, has dwindled to 3 inches, and the shale above the coal at Broadstone appears to be absent at Crawfield. There are other minor modifications, as one may expect in tracing such deposits over even limited areas, but the general aspect of the two groups can leave no doubt as to their identity in position. The Dockra Limestone, with its characteristic top, but much reduced in thickness, appears at the bridge which carries the road over the line. From this point to the beginning of the cutting the ground has been grassed over, and is somewhat obscure. But there appears to be a considerable thickness of shales, with thin ironstone bands lying between the Dockra Limestone and the limestone No. 12 in the table. Limestone No. 12 crops out at the west end of the cutting. It varies in thickness, but 1 foot may be taken as an average. The shales above and below it are fossiliferous, and we consider that this is the same band as that seen above the Dockra Limestone in the Dockra Quarry. At this point there is a greater thickness

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of strata between the two limestones, but this is probably only a local variation, and we take it as the representative of the Hurlet. This limestone is succeeded by 28 feet of shale, which are fossiliferous. On these shales rests limestone No. 14, which we consider to be the equivalent of the Blackhall Limestone. This is followed by 20 feet of shale, with ironstone balls, and 4 feet of sandstone containing plant remains. One is at once struck with the remarkable similarity of this shale, with its large ironstone balls, to that seen above the Blackhall Limestone in the Campsie and Corrieburn districts. The sandstone may also be the same as the Hosie Sandstone of these two localities. The sandstone is followed by 7 feet of shales and a limestone 2 feet 7 inches thick, which we consider to be the Main Hosie. Above this comes the Calderwood Cement, with calcareous shales above and below, the former full of brachiopods and other marine forms, the latter containing *Posidonomya corrugata* in great abundance in association with fish remains of an estuarine type and land plants.

PADUFF GLEN.—Perhaps the most complete of all the Ayrshire sections is that exposed in Paduff Glen, about three-quarters of a mile to the west of Kilbirnie station. Near the head of the glen, where the road crosses to Coldgreen Farm, a bed of shale about 8 feet thick resting upon green ashy muds, and passing up into a bed of limestone, is exposed in the sides of the stream. The shales are full of giganteid Producti, including *P. giganteus*, which are lying in the shale ventral valve downmost, as if they had flourished in placid water, and had afterwards been buried in mud, without any disturbance. The limestone contains a band of *Lonsdalei floriformis*, and is clearly the representative of the Broadstone Limestone, but approaching more closely to that seen at Lugton than at the type locality. Above this comes the Divisional Shales, with associated green ashy muds, followed by the Dockra Limestone, with its capping of ashy mud and limey nodules. The limestone has been quarried at North Dykes, but the characteristic top is best displayed in the burn section, at the base of the cliff south of North Dykes. From this point the upward succession is identical with that described in the Gurdie cutting. The somewhat diminished representative of the Hurlet Limestone is seen a little above the base of the

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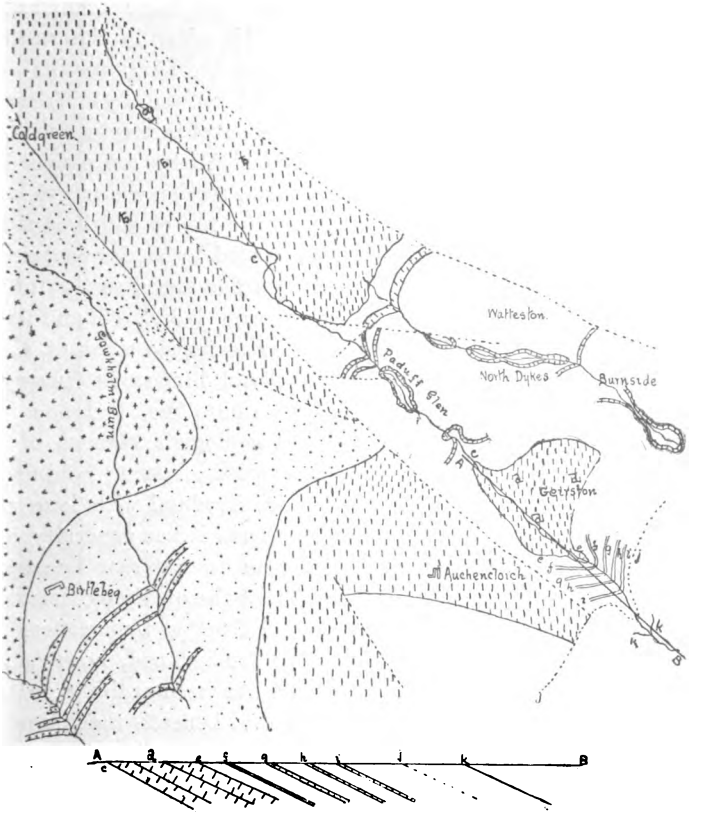
cliff, where the stream winds round it. Higher up in the cliff is seen the Blackhall Limestone, followed by the Main Hosie and the Calderwood Cement, with the associated *Posidonomya cor-*



PLAN AND SECTION ALONG LINE A B., PADUFF GLEN, KILBIRNIE.

a, Calcareous Shales resting on ashy muds; *b*, Broadstone Limestone; *c*, Divisional Shales; *d*, Dockra Limestone; *e*, Green Ashy Muds; *f*, Hurlet Limestone; *g*, Blackhall Limestone; *h*, Hosie Limestone; *i*, Calderwood Cement and *Posidonomya corrugata* Shales; *j*, Main Clay-band Ironstone; *k*, Marine Band.

rugata shales. Still further down stream comes on the Main Clay Band Ironstone, the equivalent of the Johnstone clay band, and about 30 feet higher the Productus shale and Lingula blaes,

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marking the upper limit of the marine beds, this being the same as the Johnstone shell bed and the bed already described at Netherton pit, north of Lugton, and in the Dusk Water at Dustyridge. The Dockra Limestone and those immediately overlying it are also exposed about 1½ miles to the west of Paduff Glen, in the Howrat Quarries, on the Largs road.

Hindog Glen.—This glen is situated on the Rye Water, 2 miles north-west of Dalry, where a number of interesting sections of the Dockra Limestone and Divisional Shales are exposed in the stream and in quarries. The stream section shows the lavas passing upwards into ashy muds, on the top of which is a bed of coal 8 inches thick. This is succeeded by shales containing a band of *Naidites crassa*, topped by a fine mural section of the Dockra Limestone. Further downstream the Blackband Ironstone is exposed, being brought in by a displacement of about 60 fathoms. The Cunningham Baidland Limestone Quarry is on the same horizon as the Dockra Limestone, and has long been famous with West of Scotland geologists because of the manner in which the limestone decomposes, leaving behind the remains of corals, spicules of sponges, Producti with long projecting spines, and spiral shells. Hitherto it has generally been supposed that the coal bed is the same as that seen below the Broadstone Limestone at Beith, and that the overlying limestone represented both the Broadstone and Dockra Limestones, the Divisional Shales being absent. We are inclined, however, to think that the Broadstone Limestone has been entirely cut out by overlap, and that the shales and coal beneath the limestone represent the Divisional Shales, the limestone being the equivalent of the Dockra. In a small side stream which enters the Rye Water there are exposures of the limestone which overlie the Dockra Limestone; they are identical with those described in Paduff Glen, and need not be repeated here.

Auchenskeith to Gameshill.—We do not think it necessary to follow in detail the sections exposed at Auchenskeith, at Cleaves Cove, in the Dusk Water, at Auchenmade, Auchentiber, and Gameshill, round the south-east side of the basin, and back to Lugton. For the most part these sections are confined to the lowest members of the series, and include the Broadstone

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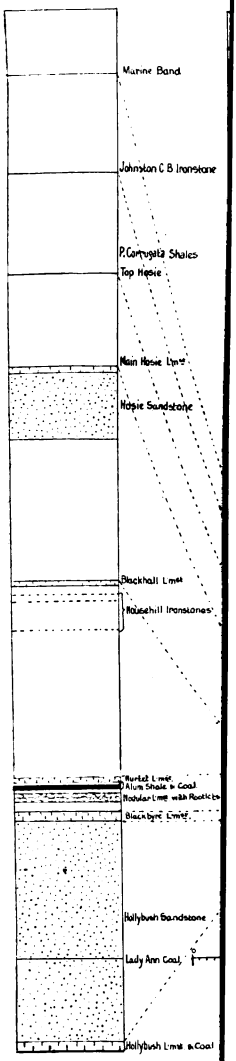
Renfrewshir

Hurlet District.



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Limestone, the Divisional Shales, and the Dockra Limestone. The section is as follows:—

Limestone rich in Brachiopods including *Streptorhynchus crenistria*,	30·0
Shale with *Naidites crassa*,	2·0
Coal,	6½
Limey Fireclay,	6·0
Shale,	2·0
Limestone, hard and crystalline,	6·0

The general palæontological aspect of the top limestone in the above table compares well with the typical Blackbyre of the Glasgow district. *Streptorhynchus crenistria* may be said to be the prevailing brachiopod, its compressed valves being crowded over each other on nearly every slab. The top limestone in the table is the equivalent of the Dockra, and the bottom that of the Broadstone in the Beith district, the strata between being the Divisional Shales. At Cleaves Cove, on the Dusk Water, and at Auchenmade, still further to the east, there are similar sections to that at Auchenskeith. At Auchenmade the basal ashy muds pass up into a coal 15 inches thick, above which is the Broadstone Limestone, 10 feet thick; this is succeeded by the Divisional Shales, which are represented by 8 feet of fireclay, 6 inches of coal, and 2 feet of shale, the whole being topped by the Dockra Limestone, 10 feet thick. The section is practically the same as at Auchenskeith. These limestones can be traced by Auchentibber and Gameshill to the outlier at Bourock, south of Lugton station.

V. Stratigraphical Considerations.

Turning now to a consideration of the general stratigraphical relationship of the Renfrewshire and Ayrshire sections, we may note, in the first place, that the various sections afford clear evidence of the existence of an important unconformity, and overlap at the junction of the limestone series and the underlying volcanic rocks. In the Craigmaddie district something like 500 feet of strata are known to lie below the Hollybush Limestone. They consist for the most part of conglomerates, grits, and sandstones, but no definite limestone horizon is known

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till the Hollybush Limestone is reached. According to the officers of the Survey, the sediments below the Hollybush Limestone reach their greatest development in the Hurlet district, where they may be considerably over 1000 feet in thickness. Though no definite palæontological horizon has as yet been established below the Hollybush Limestone, fossiliferous bands are known to exist; thus in the stream a quarter of a mile west of Hawkhead there is a band of dark limestone containing crushed remains of *Lithostrotion*, which is the lowest horizon upon which that coral has been found. We have also seen that in the Wardhouse Burn and Harelaw acqueduct at Nethercraigs there are several hundred feet of strata below the Hollybush Limestone, in which there are fossiliferous shales and ironstones. When we cross to Auchenback, Neilston, and Duniflats the limestone at these localities, which we consider to be the equivalent of the Blackbyre Limestone, is seen to rest almost directly upon the volcanic rocks, the Hollybush Limestone and the whole of the underlying strata having been cut out. This is made abundantly clear by a comparison of the railway section at Netherton with that seen on the Lugton Water, where the Dockra or Blackbyre Limestone is underlaid by the Divisional Shales resting upon the Broadstone Limestone. It is quite clear that in the short distance of about a mile not only has the Broadstone Limestone and Divisional Shales been cut out, but the Dockra Limestone has been reduced in thickness from 30 feet at Lugton to 8 feet at Netherton, and is found to rest directly upon the volcanic rocks.

On tracing this line of unconformity and overlap round the basin we find, as a rule, that the Broadstone Limestone, Divisional Shales, and Dockra Limestone are all represented. As would naturally be expected, the Broadstone or lower limestones would be liable to show the greatest variation in character. Thus at Lugton it is represented by 12 feet of calcareous shales and 5 feet of limestone, while at Broadstone, 3 miles to the west, it is a more or less massive limestone about 25 feet in thickness. It also reaches a considerable thickness in Roebank Glen. But when we cross to Paduff Burn, on the west side of the basin, the Broadstone Limestone has dwindled to 6 feet, underlain by 8 feet of fossiliferous shale. It has also been shown

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that at Netherton and Hindog Glen it has been entirely cut out by unconformity and overlap.

We are inclined to think that a similar break, though not on anything like so large a scale, has taken place at the top of the Blackbyre or Dockra Limestone. The irregular top of the limestone and the ashy mud which overlies it represent the position of a local unconformity. It seems that, after the deposition of the Blackbyre Limestone, the sea floor was elevated into a land surface, and that the strata which intervene between it and the Hurlet Limestone indicate alternating land and estuarine conditions passing upwards into marine conditions, the latter showing that the whole area was again undergoing subsidence below sea-level. If this view be accepted it would help to explain such rapid changes in the thickness of the Hurlet Limestone, such as we find in passing from Hurlet to Nethercraigs, this being due to unequal subsidence of the old land surface. It might even be advanced to explain why the limestone, having all the characters of the Blackhall Limestone at Thorntonhall, immediately overlies one having all the characters of the Blackbyre Limestone, the Hurlet being cut out by an overlap.

Another important stratigraphical feature which we wish to emphasise is the striking difference that exists in the character of the sediments below and above the Blackbyre Limestone. It has been shown that up to the green ashy mud bed that overlies the Blackbyre and Dockra Limestones ashy muds are common, and the shales, sandstones, and limestones are often tinged with green or purplish colouring matter derived from the wash of the underlying lavas. From palæontological evidence to be discussed presently we hope to be able to show that we are now in a position to definitely draw the position of the Hurlet line in the East of Scotland at the first Abden Limestone in Fife, and at a limestone lying below the Gilmerton Limestone of Midlothian.

Now, it is interesting to note that the evidence of contemporaneous volcanic action dies out just at the first Abden Limestone. We also think that there is considerable significance in the fact that the limestone seen in the Bilston Burn, south of Edinburgh, which is on the same horizon as the first Abden of

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Fife and the Hurlet of the west is underlain with a considerable thickness of ashy muds and a nodular limestone similar to those which we have described in our various sections. Passing to the sediments above the Hurlet Limestone, we are at once struck with the entire absence of these ashy muds, the characteristic sediments now consisting of shales, ironstones, and thin limestones.

An examination of the comparative vertical sections on Plate II. shows very clearly that, as the Lower Limestone series is traced from the Hurlet district into Ayrshire, they become very much reduced in thickness. The thickness in the Hurlet district measured from the Hollybush Limestone to the marine band above the Johnstone Clay Band is close on 900 feet. In the Bridge of Weir section it has been reduced to 330 feet, a little over a third of the thickness in the type district. In the Crawfield Quarry and Gurdie cutting it is only 270 feet thick, and in the Paduff Glen section the total thickness is only 170 feet, less than a fifth of the thickness in the Hurlet district. From the evidence that has been adduced we consider that there can be no doubt that the Dockra Limestone in Ayrshire is the equivalent of the Blackbyre Limestone in Renfrewshire, and that the top of the Limestone series is marked by the Calderwood Cement in both districts. This being so, the strata lying between these two horizons has been compressed in Ayrshire to something like a tenth of its thickness at Hurlet, so that with such a compression one must be prepared to meet with important modifications both in the thickness, number, and character of the limestones when compared with the Hurlet section.

VI. Palæontological Considerations.

Perhaps the most important palæontological result of our recent investigation in the West of Scotland is that which shows that now we are beginning to understand the general stratigraphy of the Lower Limestones a little better, we are thereby enabled to correlate the numerous isolated sections, and in doing so we have gradually been convinced that the various limestones and other fossiliferous horizons are characterised by

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certain faunal associations that can be more or less easily recognised.

The Hollybush Limestone horizon can generally be recognised by the presence of the large *Producti*, *P. giganteus*, *P. semireticulatus*, and *P. latissimus*, with which are associated bands of *Lithostrotion* and large solitary corals. *P. giganteus* has been recorded from the Hollybush Limestone to the Arden Limestone, that is, from the base to the top of the Carboniferous Limestone series. The relationship of the various mutations of the species is not yet well understood, and quite a number of variations are probably included under the loose specific name. The same may be said about *P. semireticulatus* and *P. latissimus*. Mr. James Neilson[13] has informed me that he can distinguish the former shell in the Hollybush from those on other horizons, and he maintains that the latter is also distinguishable from the shell that goes under the same name and is so abundant in the Index Limestone. What I believe to be another distinguishing feature of the Hollybush Limestone is the presence of limey shales almost entirely made up of the crushed remains of *Rhynchonella pleurodon*. The Hollybush horizon often contains an exceedingly rich and varied fauna, as at Craigenglen.

The Blackbyre Limestone might best be described as a shelly limestone. At the type locality it is almost entirely composed of the crushed remains of small brachiopods. If the specimens found in the walls and in the ruined houses at Blackhall can be relied upon the similarity of the limestone to that seen at the type section on the one hand and the Dockra Limestone on the other is very remarkable.

The characteristic features of the fauna of the strata lying between the Hurlet Coal and the Hurlet Limestone was referred to when we described the Howwood section. It was there shown that the shale lying immediately below the Hurlet Limestone contains a band principally made up of the two brachiopods, *Schizophoria resupinata* and *Productus semireticulatus*. Below this comes another band of shale consisting almost entirely of the remains of the four lamellibranchs, *Sanguinolites*

[13] Mr. James Neilson has gone over many of the field sections with me, and I am very much indebted to him for the great assistance he has given me on palæontological matters, on which subject he is *facile princeps* in our society.

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abdenensis, *Streblopteria ornata*, *Actinopteria persulcata*, and *Myalina Verneuili*,[14] this resting on the Hurlet Coal. This lamellibranch association has been traced in the Hurlet shale series at Glorat, near Campsie, and at Corrieburn. The above fauna has not yet been found in the Hurlet shale of the South Hill of Campsie, where the common shells on this position are *Sanguinolites* (*Leptodomus*) *costellatus* and *Pteronites persulcatus*, the former occurring in great numbers, and evidently taking the place of *S. abdenensis*.[15] The most remarkable fact is that underlying the lamellibranch band of the South Hill of Campsie, a bone bed has been discovered identical in every respect with the bone bed underlying the first Abden Limestone on the Fife coast north of Kinghorn.[16] Like it, the bone bed, which varies from 1 inch to 2 inches in thickness, is almost wholly composed of the scales, teeth, plates, spines, and bones of fishes of which no two are in juxtaposition. The bone bed is exposed in Glen Wynd a little to the west of Craigenglen, and near Baldernock. Now, if we take the fauna of the Hurlet shale as a whole we find that it consists in descending order of a brachiopod bed, a lamellibranch bed, and a bone bed, whose specific forms are identical with that found in the shale underlying the first Abden Limestone of the Fife coast.

If we turn to page 161 of the Geology of the Neighbourhood of Edinburgh[17] we find the following statement:—"The boundary line between the Calciferous Sandstones and the Carboniferous Limestone series has been drawn at the base of the Gilmerton Limestone, which in the Bilston Burn has been converted into ochre. But a considerable amount of stratigraphical and palæontological evidence has been accumulated, partly by Mr. Macconochie, which makes it not improbable that a lower limestone, the base of which, in the Burdiehouse Burn, lies 130 feet below the Gilmerton Limestone, really corresponds

[14] My identification of these four species was confirmed by Dr. Wheelton Hind.

[15] A recent examination of the section exposed in Burn Rannie, above Balgrochan, Campsie, shows the alum shale to contain a similar fauna to that at Howwood, the shale being simply crowded with *Sanguinolites abdenensis*.

[16] This bone bed was first discovered some three years ago by Mr. H. J. Conacher and myself, but its full significance was not then realised.

[17] Memoirs of the Geological Survey of Scotland, 1910.

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to the Lower Longcraig Limestone of Dunbar, which in that locality is taken as the base of the Carboniferous Limestone series. The little limestone referred to rests directly on a calcareous shale with abundant remains of *Rhipidomella* (*Orthis*) underlain by a thin pyritous shale a few inches thick, with fish remains and lingula. A shale with *Schizophoria* and *Rhipidomella* and a similar fish bed occur below the Lower Abden Limestone on the coast of Fife, which in all probability corresponds in position with the Lower Longcraig of Dunbar, though neither the shale nor the fish bed has been found in connection with it. Again, at page 169, we have, "Another important point is the correlation of these Midlothian with that on the Fife coast near Kinghorn, which Mr. Macconochie's discovery of the fish bone bed has rendered possible. From general stratigraphical relations it will be readily conceded that the thin limestone beneath the Gilmerton (and ochre bed) might represent the first or lower Abden Limestone of Fife, so that when it is found to be underlain by a shale with *Rhipidomella*, and this in turn by a bed charged with fragments of *Lingula* and fish remains, just as in the Fife section, the grounds for correlation seem reasonably conclusive. It may be noted, however, that Dr. Traquair, who has determined the fish remains present, regards the bone bed by itself as inconclusive, for much the same assemblage of forms might be expected in any bone bed about this horizon. But it is the crucial evidence that helps to fix the horizon in the stratigraphical relation of the bone bed containing *Lingula* to the shale with *Rhipidomella* and the limestones.[18]

[18] Since writing this paper I have visited the section exposed in the Bilston Burn, south of Edinburgh, under the guidance of Mr. A. Macconochie and with the anticipation that I should be able to find the lamellibranch bed between the brachiopod (*Rhipidomella*) bed of the Survey and the bone bed. My expectations were fully realised, for we were able to disinter *Sanguinolites abdenensis*, *Streblopteria ornata* and *Actinpteria persulcata* from their proper position. In my opinion this finally determines the first Abden limestone of Fife and the first limestone underlying the Gilmerton limestone of Midlothian to be the equivalents of the Hurlet limestone in the West of Scotland, and it is at this horizon that the so-called line of demarcation between the Calciferous Sandstones and Lower Limestones must be drawn (if it is to be drawn at all), and not at the present ones. I have also examined, under the guidance of Mr. R. Dunlop, the first Abden limestone on the Fife coast and I am fully persuaded that its fauna is identical in every respect with that of the Hurlet shale of the West of Scotland.

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I quite agree with Mr. Macconochie in his identification of the limestone and shale of the Bilston Burn containing the fauna just described with that of the first Abden of Fife, and I believe it to be the same as the Hurlet shale fauna of the West of Scotland. The late Dr. Traquair's remark is undoubtedly true, but I know of no other similar faunal association in the Carboniferous rocks of the West of Scotland.

I must frankly confess that I have been unable to trace anything corresponding to the Hurlet shale fauna into the north of Ayrshire. If our view of the succession there be correct it ought to appear between the Dockra Limestone and the first limestone that overlies it. A fact not without some significance is that Mr. Craig records this horizon as that in which *Sanguinolites costellatus* makes its first appearance in the rocks of the district,[19] and it has been shown that this is the common shell in the alum shale of the South Hill of Campsie.

The Hurlet Limestone itself is not generally rich in fossils, and little can be said regarding its palæontological characteristics. It is usually crinoidal, with small Productidæ, the latter occasionally being numerous enough to form bands similar to those seen in the underlying Blackbyre Limestone. But so far as our observations go this is very exceptional. The next definite palæontological horizon that we meet with in ascending order is that of the Blackhall Limestone and overlying shale. In Renfrewshire and to the north of Glasgow the limestone can be easily recognised, because it occurs in several beds—the top one crinoidal and marine, the lower entomostracan and estuarine, with partings of entomostracan oil shale. These characters cannot, however, be distinguished in the North Ayrshire sections. Above the Blackhall Limestone there occurs a group of shales in which a well-marked faunal association can be distinguished. This faunal association can be traced over a great part of the Campsie district at Thorntonhall, East Kilbride, and in the Gryffe Water, near Bridge of Weir. When the fossiliferous shale overlying the Blackhall Limestone in North Ayrshire comes to be more carefully examined we believe that it will yield evidence showing the identity of its fauna with that found in the Glasgow district.

[19] *Trans. Geol. Soc. of Glasgow*, vol. vii., p. 87.

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In ascending order the next recognisable faunal association is that associated with the Calderwood Cement Limestone. Here, again, we have an estuarine and marine type in association, the former represented by the shales containing *Posidonomya corrugata* scales, plates, and bones of fishes of an estuarine character and land plants, the marine type by the cement limestone full of brachiopods and other purely marine forms. This horizon, which is taken as marking the upper limit of the Lower Limestone, we have succeeded in tracing from the Hurlet district all over North Ayrshire and as far south as Dalry.

The marine band lying above the Main Clayband ironstone when properly searched will, I think, also yield a characteristic fauna.[20]

VII. Physical Conditions of Deposition.

The conditions of sedimentation indicated by the Lower Limestone series in Renfrewshire and North Ayrshire shows that as the irregular platform of volcanic rocks sunk beneath the sea, a great variety of types of sedimentation supervened. In the Hurlet district we have evidence that submergence of the land took place at a much earlier period than we generally find in North Ayrshire. This may have been due either to the unequal subsidence of the old land surface or to the irregularity of its platform; we are inclined to accept the latter as the most satisfactory explanation. It has been shown that marine horizons exist at least several hundred feet below the Hollybush Limestone in the Hurlet District, whereas in North Ayrshire there are practically no sediments lying below the Broadstone Limestone, which we have taken as an equivalent of the Hollybush Limestone, so that, while the sediments lying below the Hollybush Limestone in Renfrewshire were being accumulated, the Ayrshire area still remained as a land surface.

Up to the Hollybush Limestone the sediments in the Hurlet district, though probably mostly marine, do not give evidence of those intensely marine conditions indicated by the thick beds of limestone which now come on. Both the Hollybush and Blackbyre Limestones, and their equivalents in Ayrshire, the

[20] On the Fossiliferous Strata lying between the Lower and Upper Limestones in the Beith and Dalry District. Op. cit., vol. vii., p. 88.

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Broadstone and Dockra Limestones, are full of such clear water marine forms as foraminifera, corals, encrinites, echinoids, polyzoa, lamellibranchs, gasteropods, cephalopods, brachiopods, and the crushing teeth of fish, the limestones in which they occur being of detrital origin. Associated with these limestones, and often apparently replacing them, are calcareous shales, which are usually exceedingly rich in the species found in the limestones; these have been the happy hunting grounds of West of Scotland collectors. For instance, there can be no doubt that the Craigenglen Shales are on the horizon of the Hollybush Limestone. These limestones appear to have been formed of the detritus of calcareous organisms laid down beyond the reach of terrigenous sediment. The shells may be either whole or broken, and are cemented in a matrix sometimes of shell débris or of recrystallised calcite and possibly of carbonate of lime chemically precipitated together, with a varying percentage of non-calcareous material derived from other sources. Such compound corals as *Lithostrotion* and *Lonsdalea* occur in regular bands in the position in which they grew, or in nests associated with brachiopods, gasteropods, polyzoa, &c. All these features may be said to be pre-eminently characteristic of the Hollybush and Blackbyre Limestones in Renfrewshire, and of the Broadstone and Dockra Limestones of Ayrshire.

It has been pointed out that when we reach the top of the Blackbyre Limestone we find that the character of the sediments undergoes a sudden change. The succeeding limestones are generally of a darker colour and of a more calmy nature than the underlying ones, and the terrigenous deposits are no longer tinged with the green or purple ashy material derived from the old volcanic platform, but consist for the most part of dark shales abundantly charged with fossils, with which are associated clay band ironstones. All this points to a distinct physiographical change having taken place at the top of the Blackbyre Limestone, showing that the clear water coastal conditions under which the Lower Limestones were deposited had been replaced by an upheaval of the sea bottom, so that when the land again began to sink below the level of the sea, estuarine and lagoon conditions prevailed, in which river-born mud derived from the land was being deposited.

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Reference has been made to the striking evidence of land and estuarine conditions afforded by the group of strata lying between the top of the Blackbyre and the bottom of the Hurlet Limestones. There is abundant evidence that the upheaval of the sea bottom was followed by a period of local erosion. To the north of Glasgow and in Renfrewshire there is a distinct break at the top of the Blackbyre Limestone, a bed of sandstone with an irregular base marking the line of local unconformity. In Ayrshire we have shown that a similar break is seen at the top of the Dockra Limestone. The irregular top of the limestone penetrated by stigmarian roots and rootlets indicates that after elevation it must have remained for a considerable period as a land surface, upon which the green ashy mud bed was accumulated.

In the Glasgow district the sandstone just referred to is seen to pass upwards into the Baldernock Limestone. The strata between it and the Hurlet Limestone may be tabulated as follows:—

Bed.	Fossils.	Physical Conditions.	Thickness.
5. Hurlet Limestone	Crinoids and Brachiopods	Marine	4 to 6
4. Alum Shale	Brachiopods, Lamellibranchs, bone bed	Marine	2 to 14
3. Hurlet Main Coal		Land growth	4 to 5
2. Under or Fire-clay	Stigmaria	Land surface	1 to 3
1. Baldernock Limestone	*Carbonia*, *Spirobis*, Fishes	Estuarine	4 to 5

The late Dr. John Young considered the lowest of these to be of fresh-water or lacustrine origin, but the intimate association of shales and limestones almost entirely composed of *Carbonia*, with undoubted marine deposits, inclines us to think that such fresh-water conditions could not have been lacustrine, or such as would have taken place in a land-locked or inland lake basin. They rather indicate deltaic and lagoon conditions, for in such areas fresh-water forms of life would exist in the rivers and deltas, while marine forms would exist at no great distance in the sea. During flood time, or as a consequence of a slight depression of the coastline, the fresh-water deposits would extend seawards, forming alternations with marine deposits, so that estuarine rather than lacustrine would be the best definition of

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such deposits. No. 2 in the table indicates that the estuary or lagoon had become sufficiently silted up to form a land surface, upon which No. 3, the Hurlet Coal, shows the growth of a coal forest, which must have extended over a very large area of country.

The succeeding deposits show that this ancient land surface began to sink below the level of the sea, and the fauna of the alum shale indicates the transition from a land surface into deep-sea conditions. The exact physical conditions under which the bone bed was accumulated is a problem somewhat difficult of explanation, especially when we remember that the fish remains on this horizon occur in an absolutely fragmentary condition, no two separable bones or teeth being found in opposition. In this respect it closely resembles the Silurian bone bed of Ludlow on the Welsh border, which, in spite of its insignificant thickness, is known to cover an area of not less than 1000 square miles. The bone bed under consideration cannot be more than 2 inches in thickness at any of the localities at which we have examined it, yet if we take the distance from Glen Wynd to Abden as 45 miles, and across the Firth of Forth to Bilston Burn as 15 miles, it would give the bed as covering an area of 675 square miles. Of course, it is not to be supposed that the bed is continuous over the whole of this area, but the evidence that has been adduced leaves no doubt in our own mind that we are dealing with the same bed at these various localities.

The wholesale destruction of fish life over extensive tracts of the sea has been observed as due to several causes, such as earthquake shocks, submarine volcanic explosions, the driving of shoals of fishes into shallow water and against rocks by violent storms, and to the copious discharge of fresh water into the sea, by which fishes of a marine type have become destroyed in great numbers; the reverse of this has also been known to occur, in which a sudden irruption of salt water into a protected lagoon or estuary has resulted in the extinction of vast quantities of its inhabitants.

The late Mr. Goodchild,[21] when discussing the origin of the

[21] Geological History of the Coast of Fife between Aberdour and Kirkcaldy. *Trans. Edin. Field Naturalists and Microscopical Society*, session 1901-1902.

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Abden bone bed, says, "At the bottom, below the bone bed, is a lava flow. Then there is evidence of a local and apparently sudden destruction of a considerable number of fish (perhaps through some volcanic outbreak close by). Then a record of estuarine conditions, with the volcanic mud being washed into shallow water from the neighbouring volcano." It is interesting to note in connection with this explanation of the phenomena exhibited by the bone bed at Abden that the bed rests directly upon the scoriaceous surface of a lava flow, and that contemporaneous volcanic eruptions were taking place, whereas in the Campsie district the bone bed is underlaid by a considerable thickness of sediment devoid of any trace of contemporaneous volcanic rocks till we reach the top of the great volcanic platform. This shows that for a considerable period of time volcanic activity had died out in the west, while it was still active in the east.

The late Dr. Traquair[22] has pointed out that the fish remains occurring in the Abden bone bed are mostly of an estuarine character, while others are more decidedly marine. But as yet only one truly marine fish remain has occurred, namely a tooth of *Cladodus mirabilis*, so that the prevailing facies of the deposit is, so far as the fishes are concerned, decidedly estuarine. We have shown that the land surface at this period was undergoing depression, and it is quite possible that this great destruction of fish life was due to the sudden influx of pure sea water over the floor of the estuary.

The lamellibranch and brachiopod fauna of the upper part of the alum shale points to the gradual sinking of the land surface and the passage of the estuarine into true marine conditions. The succeeding Hurlet Limestone indicates a somewhat abrupt change of level into comparatively clear and perhaps deep water.

When we reach the position of the Blackhall Limestone we find that similar physical conditions to those described are again repeated. In the Bridge of Weir section a thin coal is overlaid by entomostracan limestone and shale, with fireclay full of stigmaria, which passes upwards through shale into 18 inches of encrinital limestone.

[22] List of the Fossil Fish-remains occurring in the Bone Bed at Abden, near Kinghorn, Fifeshire. *Proceedings of the Geologists' Association*, vol. xv., page 143.

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The Calderwood Limestone and Cement stone, with their associated shales, point to the recurrence of similar physical conditions. The fauna of this group testify to the extraordinary alternations of conditions under which they have been laid down, some having been inhabitants of salt, and others of estuarine waters.

The strata lying above the Calderwood Cement and belonging to the Lower Coal and Ironstone series appear to have been accumulated on an area consisting of wide alluvial flats and delta deposits, upon which river-born sediments were being deposited. A slight subsidence of the area enabled the sea to advance over great parts of it, as is shown by the top marine band, which has been traced all over Renfrewshire and Ayrshire.

VIII. Summary of Conclusions.

Stratigraphical.

1. The Broadstone and Dockra Limestones in Ayrshire are respectively the equivalents of the Hollybush and Blackbyre Limestones in Renfrewshire.

2. The four limestones which succeed the Dockra in Ayrshire are respectively the equivalents of the Hurlet, the Blackhall, the Main Hosie, and the Top Hosie or Calderwood Cement of Renfrewshire.

3. The Main Clay Band Ironstone of Ayrshire is the equivalent of the Johnstone Clay Band Ironstone of Renfrewshire.

4. The Lingula Shale and Marine Bed of Netherton Pit and Crookhill is the same as the Lingula Shale and Marine Bed of Renfrewshire.

5. The strata lying between the top of the Dockra and the Marine Band in Ayrshire have been compressed to less than the one-fifth of their thickness in Renfrewshire at Hurlet.

Palæontological.

1. The Hollybush Limestone and associated shales contain a faunal association characterised by the presence of the giganteid Producti and bands of compound and solitary corals.

2. The Blackbyre Limestone is typically a shelly limestone,

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being largely composed of small brachiopods, bands of *Lithostrotion*, and solitary corals.

3. The fauna of the Hurlet Shale, lying between the Hurlet Coal and Hurlet Limestone, is characterised by a brachiopod bed, a lamellibranch bed, and a bone bed. We believe that the fauna underlying the first Abden Limestone of Fife and the fauna underlying the first limestone below the Gilmerton Limestone, in Midlothian, to be identical with that of the Hurlet Shale of the west.

4. The lower part of the Blackhall Limestone is entomostracan and estuarine, the upper crinoidal and marine; above it there is a band of shale containing a characteristic faunal assemblage.

5. The Top Hosie or Calderwood Cement group also contains a well-marked fauna, an especial feature of which is the abundance of *Posidonomya corrugata* associated with fish and plant remains.

6. When carefully examined, the marine band above the Johnstone and Main Clay Band Ironstone may prove to contain a characteristic fauna.

Physical.

1. The junction of the Lower Limestones and the volcanics is a line of unconformity and overlap, so that, while in the Hurlet district close on 1000 feet of strata lie between the Blackbyre Limestone and the volcanics in Ayrshire, its equivalent, the Dockra Limestone, rests directly on the volcanics.

2. We believe that a similar break, though on a smaller scale, takes place at the top of the Blackbyre and Dockra Limestones.

3. There is a marked change in the character of the sedimentation above the Blackbyre Limestone. Below that horizon the limestones generally indicate clear-water coastal conditions, and the sediments are often tinged with colour from the underlying lavas. Above it the limestones are of an impure or calmy type, and the associated sediments are commonly dark shales and ironstone.

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EXPLANATION OF PLATE XXVII.

Fossils from the Shale lying between the Hurlet Coal and Hurlet Limestone, Howwood, Renfrewshire.

1. *Schizophoria (Orthis) resupinata* (Mart.).
2. *Productus semireticulatus* (Mart.).
3. *Sanguinolites Abdenensis* (R. Ether, Jun.).
4. *Actinopteria (Pteronites) persulcatus* (M'Coy).
5. *Myalina verneuli* (M'Coy).
6. *Streblopteria ornata* (R. Ether, Jun.).

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No. XVII.—The Lower Limestones of Renfrewshire and North Ayrshire: A Comparison and Correlation.

By R. G. Carrruthers and J. E. Richey (of H.M. Geological Survey).

[Read 14th May, 1914.]

The primary object of the present communication is to suggest a correlation of the Lower Limestone group between Renfrewshire and Ayrshire. The sediments of these two areas are no longer in direct continuity: whatever may have been the case in the past, they are now separated by a belt of the underlying lavas. As a consequence no horizon can be followed without interruption from one district to the other: the correlation must remain a matter of inference alone.

The method followed has been to examine the sequence as developed in each area, and to use as a basis those horizons which retain their peculiarities throughout the region: one can naturally expect that these "constants" should pass over from one district to the other, and especially so in view of the fact that the upper parts of each sequence are sufficiently alike to warrant the belief that the two areas were in complete communication when those sediments were originally deposited.

A glance at the published maps will show that the limestone strata of the two districts approach each other closely at two points. The first is by way of the long trough running southwest from Barrhead through Neilston to Lugton; the second is in the similar depression passing through Castle Semple Loch from Howwood to Lochwinnoch. A comparison of the limestones of Barrhead and Lugton has the advantage that the type succession of the Lower Limestone group comes from Hurlet, close to Barrhead; nevertheless, although the sequence is there well known from mining evidence, the limestones themselves are very poorly exposed, and their peculiarities cannot be closely studied; furthermore, at Lugton the North Ayrshire succession is highly compressed, and can only be pieced together with difficulty.

The comparison is a much easier matter through the Loch-

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winnoch Valley. To the north there is not only a fair sequence at Howwood, but in close proximity lies the Bridge of Weir country, affording the best natural sections in Renfrewshire, and where there can be no reasonable doubt about the correlation with Hurlet; while at the south end of the valley there are excellent field exposures of the Ayrshire sequence, all of which can be closely examined. It is therefore by way of Lochwinnoch that the correlations will be attempted.

A complete succession of the Lower Limestone group in Renfrewshire cannot be worked out from any single field section, although it is given in several bores and pit sections. There are, however, many isolated exposures of all the strata below the Lillie's Shale Coal, and in the Gryffe Water below Bridge of Weir there is a practically complete section from the Mid-Hosie Limestone down to the Hurlet seam. The following is the sequence of limestones: unless otherwise mentioned, the intervening strata consist solely of blaes, the relative distances between the horizon being indicated in the sections on Plate XXIX.:—

THE RENFREWSHIRE SEQUENCE.

Johnstone Shell Bed.—Originally noted in 1870, by the Survey, at the Inkerman Pits, N.E. of Johnstone. The Survey collections, particularly those from another pit, at Corkerhill, east of Paisley, show that it is a highly fossiliferous blaes, the upper part full of *Lingula*, the lower rich in small *Producti*. There are a few fathoms of sandstone below.

Johnstone Clayband.—A regular bed of ironstone—still worked at the Walkinshaw, Corkerhill, and Nitshill Ironstone Pits.

Top Hosie Limestone.—Nowhere exposed *in situ*, but old workings at Locher Mill (E. of Bridge of Weir) and Tweeniehills, and the pit sinking at Corkerhill, show that it is a dark, calmy limestone with strings of small gasteropods and brachiopods, well preserved. *Posidonomya corrugata* is abundant in the surrounding shales. Immediately below there is good evidence, at Locher Mill, of the presence of another limestone of a normal

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crinoidal type, associated with limy blaes full of crushed brachiopods and encrinites.

Lillie's Shale Coal.—Only known exposure is at Locher Mill, where a foot of soft coal rests on a foot of laminatel cannel or parrot coal. Here there is a 3-foot bed of sandstone below.

Mid-Hosie Limestone.—A grey limestone full of small crinoid débris. Seen in the Gryffe Water above Crosslee (E. of Bridge of Weir) and in the Locher Burn to the south at several points. The blaes above contains *Sanguinolites* and small goniatites.

Main Hosie Limestone.—Similar in type to the Mid-Hosie, and seen at the same localities. The blaes above the limestone is also rich in small goniatites.

Blackhall Limestone.—Frequent exposures (Levern Water below Hurlet, old quarry at Blackhall, Gryffe Water above and below Crosslee, &c). The limestone itself is crinoidal, and may contain small zaphrentid corals (Gryffe Water, E. of Bridge of Weir, and Howwood boring). Immediately below there is a nodular cement,[1] white or greenish, with non-marine entomostraca and rootlets, followed by bands of entomostracan shale and limestone. Overlying the crinoidal limestone is a highly fossiliferous blaes (the Neilson Shell Bed),[2] with a great variety of small brachiopods, and small gasteropods, goniatites, and *Orthoceras*, all in excellent preservation. This is the richest fossil bed in the Lower Limestone group, and affords a sure index to the Blackhall position. It is well exposed in the Gryffe Water, and was also got in the Howwood boring.

Hurlet Limestone.—A seam constant in position, but very variable in thickness, and to a less extent in character also. Generally a hard crinoidal limestone 2 or 3 feet thick. A parting of "alum shale" separates it from the coal below,

[1] In this paper, the term "cement" is used for a compact argillaceous limestone with porcellanous fracture.

[2] The name is suggested because this horizon was first brought into prominence by Mr. James Neilson, of Glasgow, who collected from it extensively at Campsie, and at Thorntonhall, near East Kilbride. Mr. Neilson used the fossil band as a leading datum in certain identifications of the Blackhall (Hosie) Limestone, from which, at first, I strongly dissented, but which I now believe to be correct. He has set forth his argument at length in a recent paper (*Trans. Geol. Soc. Glasgow*, vol. xiv., Part III., pp. 327-336, 1912.)—*R. G. C.*

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which is generally 4 to 6 feet thick. Exposures at Arkleston, Blackhall, Limecraigs, Bridge of Weir, and Howwood.

The White or Baldernock Limestone.—There are 1 or 2 fathoms of fireclay below the Hurlet coal, resting on a nodular cement limestone, white or greenish in colour. This is a marine horizon, but varies greatly in character. East of Paisley (Crookston, near Hurlet, and Arkleston) the limestone contains rootlets, marine entomostraca and *Spirorbis*, but to the west brachiopods, and even corals (*Syringopora*), also occur (Howwood and Bridge of Weir). At Limecraigs the position may perhaps be represented by strings and nodules of unfossiliferous cement stone embedded in red marls.

Blackbyre Limestone.—Separated from above by 5 or 6 fathoms of blaes, marl, and fireclay; does not contain corals, but is in the main a brachiopod limestone or limey blaes full of small *Producti* and crinoid ossicles; rests on 1 or 2 feet of pale mudstone with "*Naiadites*" (Barrhead, Blackhall, Limecraigs) and (at Bridge of Weir) *Posidonomya becheri*, *Actinopteria*, *Pinna*, &c. There is a foot or so of foul coal below. Exposures at Barrhead, the Caledonian Railway cutting near Blackhall, Limecraigs, and Gryffe Water. Under the Blackbyre are 10 to 20 fathoms of sandstone and marls with one or more thin coals (Lady Ann coal). The only complete exposures of these strata are at Limecraigs, south of Paisley.

Hollybush Limestone.—A grey earthy limestone 5 to 15 feet thick, abundantly fossiliferous, containing *Lithostrotion* and cup corals, *Spirifer*, *Productus*, &c. (Hollybush, Hawkhead, Seedhill, Bridge of Weir, Howwood). With the local exception of the "White Limestone," this is the only *Lithostrotion* limestone of the district. At Seedhill, between the limestone and the coal below, there is a black slate with *Lingula*. Strata mostly red marls for 20 fathoms below (Limecraigs and Dykebar district).

There are several points with regard to the above sequence of strata which call for further remark. The Johnstone Shell Bed has a very wide distribution. It is not only known throughout Renfrewshire, but extends north of the Clyde and eastwards beyond Carluke, at least as far as Wilsontown,

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Amongst the Hosie limestones the greatest individuality is certainly exhibited by the Top Hosie Limestone. This seam retains its distinctive characters (a dark, calmy limestone, with small gasteropods, &c., and with *Posidonomya corrugata*[3] in the shales immediately above and below), not only throughout Renfrewshire, but northwards into the Campsie district and eastwards through the South Lanarkshire Basin, up to Carluke or beyond. The Lillie's Coal has an equally wide range, and it should be noted that it is the only coal position amongst the Hosie Limestones. The two lower Hosies, although constant in position in Renfrewshire, have no marked peculiarity, and the associated goniatite beds found at Bridge of Weir are, we believe, only local; they are certainly not present as such at Campsie and in South Lanarkshire. The case is different with regard to the Blackhall Limestone, which presents a highly characteristic association of sediments. The sequence here—Neilson Shell Bed, crinoidal limestone, entomostracan shales, with a band of green or yellow marl and cement—holds good all over the Glasgow district, and also extends into South Lanarkshire. While we do not consider that the Neilson Shell Bed contains any fossil restricted to this horizon, still it is undoubtedly remarkable for the richness, variety, and fine state of preservation of the fauna. The crinoidal limestone below is always thin (up to 2 feet thick), but, as one might expect, the non-marine strata beneath show greater variation: thus the cement may be 3 or 4 feet thick at Campsie, but at Hurlet is represented only by a greenish yellow marl, in which strings of cement nodules reappear at Bridge of Weir and Howwood.

The Hurlet seam has no individual peculiarity, its recognition depending rather upon its relation to the adjacent strata. It may be noted, however, that towards Ayrshire the limestone increases rapidly in thickness, and the coal shows a corresponding diminution. Thus, an average section between

[3] Mr. Etheridge (*Mem. Geol. Surv.*, Explanation of Sheet 23, p. 103), first showed that this fossil was particularly developed at the Calderwood Cement or Top Hosie position. His conclusions have recently been confirmed and greatly extended by Messrs. Macnair and Conacher ("On the Distribution of *Posidonomya corrugata*," *Trans. Geol. Soc. Glasgow*, vol. xiv., Part III., pp. 309-322, 1912).

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Hurlet, Johnstone, and Campsie would be—Crinoidal limestone, 3 feet; coal, 4 feet; while at Bridge of Weir, and also at Limecraigs, south of Paisley, the limestone is about 30 feet thick, and of a very calmy and flaggy character, with only a few crinoids and *Producti*. At Howwood (the nearest exposure to Ayrshire) the section is—

	Ft.	Ins.
Blaes, unfossiliferous,	—	—
Bands of crinoidal limestone embedded in limey blaes with an abundance of large crinoid stems; some small Producti and Polyzoa (*Tabulipora*),	30	—
Hard, creamy, crinoidal limestone,	6	—
Dark blaes, with crushed Producti and lamellibranchs,	1	—
Coal—pyritous,	1	4
Fireclay,	—	—

The blaes between the limestone and coal in the above section represents the "alum shale," which is, as a rule, relatively unfossiliferous (at Arkleston and Blackhall, east of Paisley, small *Lingulæ* only are present). The identification of the Hurlet Limestone at Howwood and Bridge of Weir is based, not on any character in the seam itself, but on the fact that the white and green marine nodular limestone lies below, while above there is the still more characteristic Blackhall position (Gryffe Water and at Howwood in a recent boring). The 36 feet of limy blaes and limestone here representing the Hurlet Limestone is by far the thickest marine position in the Lower Limestone group of the district.

The Hurlet Limestone resembles the Blackhall in having entomostracan and fish bearing beds below, but the blaes immediately above, in contrast with the Neilson Shell Bed, is noticeably barren of fossils. In the Bridge of Weir-Howwood region there are two thin coals between the Hurlet and Blackhall Limestone, and the fact should be emphasised that, with the possible exception of an inch or so of *Lingula* shale, all the strata between these limestones are of a non-marine character.

The strata below the Hurlet Limestone do not call for further mention here, since their recognition in Ayrshire is probably a doubtful matter owing to their overlap on the lavas. In the Survey Memoir on the Glasgow District it was demonstrated that for a considerable period after their ejection, the Calciferous

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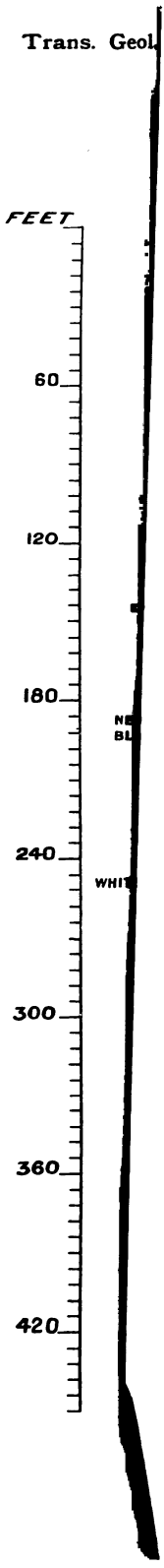

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lavas stood out as great land masses in the Carboniferous sea, and that it was not until the Hurlet Limestone was being deposited that open water swept over the region.[4]

Of this state of affairs there is excellent evidence in Renfrewshire. Again and again do we find the sedimentary sequence below the Hurlet curtailed by overlap. Thus at Kilbarchan the Quarrelton Coals rest on the lavas: at Bridge of Weir the basal sediments occur just under the Hollybush Limestone; while a more extreme case was met with in the recent Meikle Corseford boring, near Howwood, where the "White Limestone" in the floor of the Hurlet seam was found resting directly on the volcanic rocks. Furthermore, the overlap is shown, not only by direct stratigraphical evidence, but also by the pronounced colouration so frequently seen in the sediments up to the Hurlet position—a colouring due to the presence of decomposed volcanic material washed off the old land surface. Dark blaes, of the normal Carboniferous type, is a comparatively rare feature below the Hurlet, but immediately above that position comes on in strong force; in fact, the first 40 fathoms of strata above the Hurlet consist almost entirely of dark blaes with thin bands of coal, limestone, and ironstone, the only exception being the foot or so of greenish marl under the Blackhall Limestone. The change of sedimentation above the Hurlet position is indeed a very striking one, and it strongly supports the stratigraphical evidence that, during and after the deposition of the Hurlet Limestone, there was a complete submergence of the lavas, permitting of a free communication between Renfrewshire and Ayrshire.

THE NORTH AYRSHIRE SEQUENCE.

In North Ayrshire the determination of the Lower Limestone succession rests not so much on mining evidence as on the excellent field sections available. In that respect the region compares favourably with Renfrewshire. One of the best sections is seen in the Paduff Burn, between Dalry and the

[4] "The Geology of the Glasgow District," p. 13; *Mem. Geol. Surv.*, 1911. See also the vertical sections on the accompanying one-inch map.

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Lochwinnoch valley. The major portion of the Ayrshire sequence is here displayed, the details being as follows:—

	Fms.	Ft.	Ins.
SHELL BED.[5] Richly fossiliferous blaes, the upper part with *Lingula*, the lower with small *Producti*, &c., - - - - - about	1	—	—
Blaes, - - - - - - - - - about	2	3	—
DALRY CLAYBAND IRONSTONE, - - - - -	—	1	—
Blaes, - - - - - - - - - about	7	—	—
Calcareous blaes with *Posidonomya corrugata*, -	—	—	½
Calcareous blaes, with entomostraca, - - -	—	—	3
LIMESTONE D. A calmy, shelly limestone, -	—	—	9
Calcareous blaes with marine fossils, - - -	—	1	6
Calcareous blaes with entomostraca, - about	—	—	6
Calcareous blaes with *Posidonomya corrugata* and lamellibranchs, - - - - - - -	—	1	—
Blaes, - - - - - - - - - about	—	—	6
Calcareous blaes with abundant marine fossils, -	—	1	3
LIMESTONE C. Encrinital, - - - - -	—	3	—
Clayband Ironstone, impure, with fish and entomostraca, - - - - - - -	—	—	6
HOSIE FIRECLAY, with rootlets, - - - -	—	5	—
Calcareous blaes with a fair number of marine fossils, - - - - - - - - -	—	3	—
LIMESTONE B. Encrinital, - - - - -	—	2	—
Blaes, - - - - - - - - -	—	3	—
Blaes, with *Lingula* above and well-preserved Goniatites below, - - - - - -	1	—	—
Calcareous blaes, with a good variety of marine fossils, - - - - - - - -	—	—	9
LIMESTONE A. Encrinital, - - - - -	—	—	6
Calcareous blaes with marine fossils, - - -	—	—	9
Blaes, with clayband ironstone with fish, - -	1	1	—
Green marl, with fish and rootlets, - - -	—	—	10
DOCKRA LIMESTONE,[6] with irregular red top studded with roots, - - - - -	—	—	—

This sequence is identical in its main features with that ex-

[5] R. CRAIG. "Fossiliferous Strata lying between the Lower and Upper Limestones. Dalry and Beith." *Trans. Geol. Soc. Glasgow*, vol. vii., 1885, p. 90.

[6] For the Dockra Limestone, various synonyms have been used by the late Mr. Robert Craig and others. The names "Hillhead" and "Trearne" are, however, no longer suitable, owing to the disappearanee of the quarries at these places, while "Auchenskeith" and "Howrat" have been taken to include also the Broadstone Limestone. A new name, "Dockra," has therefore been chosen, on account of the fine quarry exposure at this place.

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posed in the railway cutting east of Glengarnock until the beds below Limestone A are reached, which are here as follows:—

	Fms.	Ft.	Ins.
Blaes, with entomostraca and fish, - about	2	—	—
Fireclay, dark marly, upper part greenish, - -	—	2	—
Blaes, with clayband ironstones, resting immediately on the Dockra Limestone, - about	9	—	—
Dockra Limestone. Top band red, without rootlets, - - - - - - seen	—	4	—

In the Dusk Water near Hessilhead and the Lugton district the Paduff sequence is followed, except that Limestones A and B cannot be individually distinguished. At Lugton they are represented only by a few feet of blaes full of marine fossils. Also, it should be noted that in the Lugton district the top Limestone D is cement-like in character, *Posidonomya corrugata* being rare or absent in the blaes above, and not found below.

In North Ayrshire generally the Dockra Limestone is thick, averaging about 30 feet. It occurs in two main facies in the district dealt with. One is pale or white in colour, with bands of limey blaes, built up more or less of large encrinites and brachiopods (Dockra, Trearne, Dusk Water, near Hessilhead, Lugton, near Giffen Station, Auchenmade, Auchenskeith, Dusk Water near Blairmill, Cartleburn, and westwards of Dalry as far north as Howrat); the other is a dark bedded limestone, poor in fossils, ending with a creamy-coloured post above (Paduff Burn, Pundeavon Burn, and Glenlora). The transition from one facies to the other can be established at Lugton and Howrat. Below the limestone is a few feet of blaes with pyritized *Producti*, &c. (Dusk Water, near Hessilhead, Auchenmade), followed by a coal up to 1 foot 9 inches thick (at Lugton). The beds below the Dockra coal may be examined in the Dusk Water section near Hessilhead and in the quarries near Broadstone, and include three limestones. The section is as follows:—

	Fms.	Ft.	Ins.
Dockra Limestone and Coal, - - - - -	—	—	—
Fireclay, with limey balls, - - - - - -	—	5	—
Coal (at Broadstone, blaes 15 ins.), - - - -	—	—	6
Fireclay, - - - - - - - - - -	—	3	—
Sandstone, - - - - - - - - - -	—	5	6

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	Fms.	Ft.	Ins.
WEE POST. Encrinital,	—	1	9
Calcareous blaes, with *Naiadites crassa* at Broadstone,	—	—	3
Coal,	—	—	9
Black fakes (dark fireclay at Broadstone),	—	2	—
BROADSTONE LIMESTONE. The rock is dark, with numerous *Lithostrotion* bands, but never has the fossiliferous character of the Dockra Limestone of the neighbourhood, about	3	3	—
Calcareous blaes with a varied marine fauna, with *Naiadites crassa* in its lower part at Roughwood (also at Lugton),	—	3	—
Coal, at Broadstone,	—	1	4

The Broadstone Limestone and underlying beds down to the Calciferous Sandstone lavas are exposed in the fine railway section east of Barrmill, which is somewhat as shown below—

	Fms.	Ft.	Ins.
Fireclay, green marly, with calcareous balls,	—	3	—
BROADSTONE LIMESTONE, about	4	—	—
Calcareous blaes, with pyritized *Producti*, &c.,	—	3	—
Coal, seen	—	1	—
Gap, about	2	—	—
Marl, ochreous,	2	3	—
Sandstone, green compact calcareous,	—	4	—
Gap,	—	1	—
LIMESTONE. Coarsely encrinital, green and white, seen	—	—	5
Gap,	1	3	—
Marls, grey and variegated with green sandstone, about	5	1	—
Blaes, with clayband ironstone,	—	4	—
Cementstone, marly, with fish,	—	—	7
Limestone, with brachiopods and lamellibranchs, fish scales at base,	—	—	9
Coal,	—	—	6
Fireclay, black faky,	—	—	6
Marls, variegated and green, with green sandstone,	7	2	—
Mudstones, red,	3	3	—
Gap,	1	1	—
Mudstones, red,	4	—	—
CALCIFEROUS SANDSTONE LAVAS,	—	—	—

Overlap of the Limestone Series on to the Calciferous Sandstone Lavas.—A comparison of the sections on the plate shows

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that an abrupt lithological change takes place at the top of the Dockra Limestone. At this point a thick blaes series begins, and extends above the Dalry Clayband Ironstone, broken only by thin limestones and a little fireclay and sandstone. On the other hand, the strata below the Dockra consist chiefly of marls and sandstones with thick limestones, little or no blaes being developed. These beds are all apt to change and disappear.

The Broadstone Limestone, for example, keeps its normal character and associations as described above from Crawfield, east of Glengarnock, to the Dusk Water near Hessilhead, and from Auchenmade to Roebank Glen. But east of the Dusk Water at Lugton it is represented by a green limestone resting on greenish fossiliferous blaes with limestone nodules with ochreous marls above, in which a calcareous parting overlying a coal indicates the Wee Post position. North-east of Lugton, in a remarkable section along the Caledonian Railway, the Dockra Limestone is reduced to a few feet in thickness, and rests almost directly upon the Calciferous Sandstone lavas, while the beds between, about 37 fathoms thick near Barrmill, are practically absent. Again, near Gameshill, all the limestones below the Dockra Limestone are missing, a few feet of marl separating the Dockra Limestone from the lavas. Along the entire western side of the Dalry basin the Broadstone Limestone has only been recognised in the Paduff Burn, where it is reduced in thickness and associated with marls as at Lugton. In all the other sections as far north as Glenlora the Dockra Limestone, with its lower parts tinged with green or containing pebbles of igneous rocks, rests directly on conglomerates and marls that lie above the Calciferous Sandstone lavas.

These observations indicate a progressive overlap on to the Calciferous Sandstone lavas, terminating, so far as one can judge, during the period of deposition of the Dockra Limestone. No section is known where this limestone is completely absent, and, moreover, above it, no deposit, such as might be derived from the wash of the lavas, has been seen in any section, apart, perhaps, from the strip of green clay lying immediately upon the limestone.

Through the part of North Ayrshire examined it is easy to

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recognise the shell bed above the Dalry Clayband Ironstone, the Clayband Ironstone itself, and Limestones D and C. Individual distinction of Limestone A is a general feature of the region, although it only holds in two of the sections figured. The Dockra Limestone, although presenting two distinct facies, is always easily determined. It is not only much thicker than any limestone above, but it is invariably marked by an abrupt upward transition into non-marine strata, a change frequently indicated by a green marl band at the top of the limestone. There is also another thick limestone in Ayrshire, namely, the Broadstone, but this can always be distinguished from the Dockra by the totally different sediments above these limestones, sediments that keep their character for the whole area. Reviewing the Ayrshire sequence as a whole, it will be noted that a change of sedimentation occurs at the Dockra Limestone, the limestones above being mostly associated with blaes, those below chiefly with marls and sandstones: this lower series is very subject to variation as a result of overlap on the underlying lavas.

CORRELATION.

In comparing the limestone sequences of Ayrshire and Renfrewshire, we take it that there can be no question as to the equivalence of the highest datum line in each region, namely, the Johnstone Shell Bed of Renfrewshire and the *Lingula* and *Productus* shale of Ayrshire. Each of these has a great non-marine group of coals and ironstones above (Dalry Coals and Ironstones in Ayrshire, Possil Coals and Ironstones in Renfrewshire), while below there is a thick and regular seam of clay-ironstone (Johnstone Clayband of Renfrew, Dalry Clayband of Ayrshire). The Lower Limestone group proper underlies this ironstone in each case.

The next broad point of resemblance in both regions is the abrupt change of sedimentation towards the lower part of the limestone sequence, the sediments below this line being affected, both as to the composition and lateral extension, by overlap on to the lavas, while those above are regular, and show practically no trace of the close proximity of any land surface. In Renfrewshire this change takes place at the Hurlet Limestone

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position, in Ayrshire it occurs at the Dockra Limestone. On this ground alone a provisional correlation between these two limestones may be suggested, for the two regions are sufficiently close to warrant the belief that such a profound physical change was synchronous over the whole area. It now remains to consider whether this approximation is borne out by a systematic comparison of the strata in each region, from the Johnstone Shell Bed downwards.

In Renfrewshire the first marine horizon below the Johnstone Shell Bed is the Top Hosie or Calderwood Cement. As noted previously, this is a dark, calmy limestone, with *Posidonomya corrugata* above and below. In Ayrshire the first marine horizon (Limestone D) is of an identical nature, so that these can be correlated without much hesitation. Again, in both Renfrewshire and Ayrshire there is a marine limestone (Limestone C in Ayrshire) immediately below the Top Hosie and Limestone D respectively. These, then, may be regarded as equivalent, especially when it is found that, in Renfrewshire, the next horizon below is the Lillie's Shale Coal, while in Ayrshire, immediately below Limestone C there is also a coal position, usually represented by a fireclay (the Hosie Fireclay), but sometimes accompanied by coal as well. In both cases it is to be noted that this is the first coal position below the Johnstone Shell Bed.

So far correspondence between the two regions is excellent. The underlying strata are not quite so satisfactory. In Renfrewshire, between the Lillie's Coal and thick Hurlet Limestone, there are three thin crinoidal limestones. The two upper seams (Mid and Main Hosie) have no particular characteristics, but the lower (the Blackhall) is clearly defined by its association with a rich marine horizon (the Neilson Shell Bed) above and non-marine entomostracan cements and shales below. Now, in Ayrshire only *two* marine horizons (A and B) at most can be established between the Hosie Fireclay and the great Dockra Limestone. Guided by the number of the limestones alone, one must conclude that A and B represent the Main and Mid Hosie, while the third, or Dockra Limestone, must correspond with the Blackhall. This leaves either the Wee Post or the Broadstone Limestone to represent the Hurlet.

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Against this interpretation there are grave objections. There is not only the great thickness of the Dockra Limestone to be considered, but one also has to remember that immediately above the top of the Dockra, far from there being any horizon to represent the Neilson Shell Bed, there is, on the contrary, an abrupt passage into non-marine strata. Another point, of lesser importance, is that there is no ostracod horizon below the Dockra in any way comparable with that found under the Blackhall. It is clear, then, that a correlation based on the number of the limestones alone is hardly practicable.

There is an alternative interpretation, namely, that the Mid and Main Hosies are jointly represented in Limestone B, while Limestone A corresponds with the Blackhall. This view presents far less difficulty. A fusion of limestones may always be expected in Ayrshire, because the sequence is, relatively to Renfrewshire, a compressed one, while Limestone A not only resembles the Blackhall in the presence of small zaphrentid corals, but still more so in the possession of a very fossiliferous marine blaes above and non-marine entomostracan shales below. These strata, although by no means so strongly defined as those accompanying the Blackhall Limestone in Renfrewshire, do nevertheless provide an essentially similar sequence.

According to this view, the Dockra Limestone, next below A, would be correlated with the Hurlet. The conclusion so reached is greatly strengthened when one finds that towards Ayrshire the Hurlet Limestone thickens greatly, becomes full of large encrinites, and passes abruptly upwards into non-marine strata, just as the Dockra does in Ayrshire. Furthermore, the reading coincides with that previously arrived at by the consideration that the termination of overlap phenomena and the oncoming of new sedimentary conditions, so sharply marked in both Ayrshire and Renfrewshire, were probably synchronous. The existence of a land barrier between these two regions explains the absence of any good representative of the "White (Baldernock) Limestone" below the Dockra in Ayrshire. The whole argument is illustrated graphically by the diagram-section accompanying this paper (Plate No. XXX.).

Beyond the two alternative correlations discussed above, no other seems to be admissible, in view of the facts observed. We

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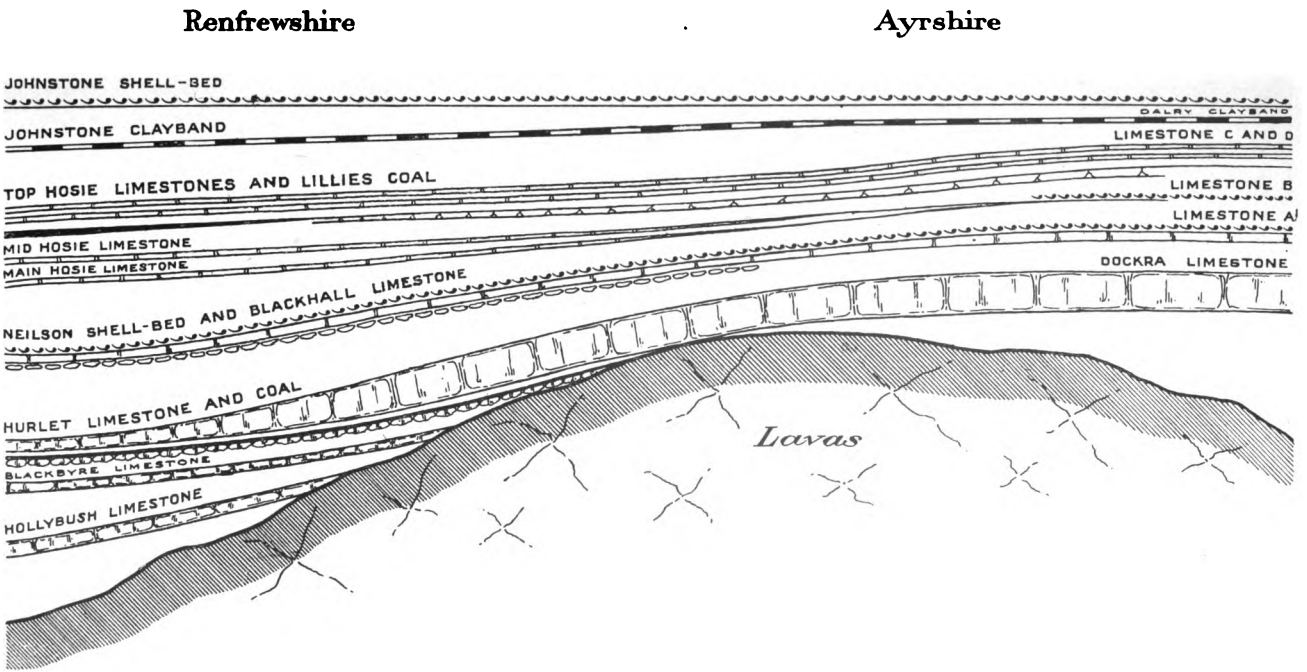

Diagram-Section illustrating correlation and overlap in the Lower Limestones of the West of Scotland.

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have no hesitation in preferring the second hypothesis, and in fixing on the Dockra Limestone as the representative of the Hurlet in the Ayrshire succession.

Addendum.

As this MS. goes to press, the latest number (vol. xv., Part I.) of the *Transactions* of this Society has been published, containing an article by Mr. Macnair and Mr. Conacher on "The Stratigraphy of the Limestones lying immediately above the Calciferous Lavas in the Glasgow District." The greater part of the paper deals with Renfrewshire and Dumbartonshire alone, but the authors take the opportunity to present a reading of the Ayrshire sequence (*loc. cit.* p. 43), with which we are not in agreement.

They correlate the Broadstone Limestone with the Hollybush, and the Dockra with the Blackbyre, while "the Hurlet, in the north of Ayrshire, has dwindled to less than its thickness in the type section," *i.e.*, it is either Limestone A or Limestone B of the Paduff section. This means that the Mid and Main Hosies have gone altogether, or even the Blackhall Limestone also; and, further, the reading is totally against the Renfrewshire evidence, which shows that the Hurlet, far from thinning towards Ayrshire, rapidly thickens out in that direction (Bridge of Weir, Limecraigs, and especially Howwood) to 30 feet or more.

As regards the Blackbyre and Hollybush position in Ayrshire, we do not believe that any sound correlations can be made, because in Renfrewshire the colouring of the sediments from lava wash, and an irregular overlap on to the lavas themselves, persists right up to the Hurlet Limestone. There is accordingly every reason to suppose that the barrier of lavas between Ayrshire and Renfrewshire was not broken down till Hurlet time, and so it is improbable that the Blackbyre and Hollybush Limestones were ever directly continuous into Ayrshire.

Their discovery of *Posidonomya corrugata* in the highest of the Lower Limestones is an important point, and we agree with their use of this fossil as an index to the Top Hosie position. There is no doubt that this bed has a wide distribution in North Ayrshire.

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The Renfrewshire portion of the paper is in the main excellent, especially when one considers the wide stretch of country under review. A brief critical analysis of this part, so far as it affects our present work, is given below.

Howwood.—We agree in the confirmation of the original Survey identification of the Hurlet Limestone, and with the recognition of the Hollybush, but the burn section at Meikle Corseford is greatly disturbed, and we believe that the Blackbyre Limestone is faulted out altogether, the green and white nodular limestone being only the White (Baldernock) Limestone in a more marine phase than usual (as at Bridge of Weir).

Bridge of Weir.—We agree with the identification of the Hurlet, Hollybush, Baldernock, and Blackhall Limestones, the last three being new points of great value. The presence of the Blackbyre is deduced by a somewhat free interpretation of an old boring at Goldilee. As a matter of fact, the characteristic dark *Productus* shales of that position are well exposed on the south bank of the Gryffe, immediately above the ford. The authors are also clearly of opinion that the Top Hosie Limestone is seen further downstream, but the two limestones there exposed are the Mid and Main Hosies, the Lillie's Coal and Top Hosie never entering the river section.

Limecraigs (Nethercraigs *auctt*).—We agree entirely with the reading of this most interesting section, except in two points. In the first place, we are not satisfied that the nodular cement a few feet above the Blackbyre does actually represent the Baldernock Lime, which may be some distance above, obscured by quarry débris. In the second place, the statement that "At Nethercraigs the burn section goes only a short distance below the Hollybush, showing nothing but sandstones," is erroneous. In reality 300 feet of strata outcrop in the stream east of the quarries, all these beds lying below the Hollybush, and containing several important horizons not seen in conjunction elsewhere. The completeness of this section is unique in the Glasgow district. (See p. 71 of the "Summary of Progress" for 1913.—*Mem. Geol. Surv.*)

Apart from the above, the paper is of great value, and marks a very considerable extension of, and improvement on, the recent survey work around Glasgow.

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PROCEEDINGS OF THE GEOLOGICAL SOCIETY OF GLASGOW.

SESSION 1912-1913.

Fifty-Sixth Session.

REPORT OF THE COUNCIL FOR 1912-13.

The Council have again to submit their report upon the work and events of last Session, the fifty-fifth of the Society's existence.

During the past year the Membership of the Society has, unfortunately suffered a somewhat severe depletion, there having been fourteen resignations and five deaths. It will therefore be necessary that every member should use his utmost endeavour to add to the membership, as it is only by doing so that the efficiency of the Society can be maintained. It would be an extremely regrettable thing if we were to fall away from the high standard which we have kept for over fifty-six years. The most serious aspect of the outlook is that our *Transactions* are bound to suffer through want of funds. The problem has been temporarily solved by a very liberal contribution to the publication funds by a friend; but we cannot always expect to get such a friend in need, and if the present standard of publication is to be kept up, it is absolutely necessary that we should have an increased membership. As on previous occasions, your Hon. Treasurer, Mr. E. Hall Wight, will submit his report upon the financial position of the Society, and your Hon. Librarian, Mr. Wm. Sinclair, his report upon the library.

During the byegone Session many papers and notes upon specimens of interest were submitted to the Society at its meetings, which were eight in number, most of which were largely attended. Dr. John Horne, F.R.S., President of the Society, opened the Session with an address upon "Sweden in Glacial and Post-Glacial Times." Among the more important papers read were—"The Old Channel of the Tillon Burn, Motherwell," by Mr. R. W. Dron; "An Occurrence of Dolomitic Limestone in Glen Fruin," by the late Mr. Russel F. Gwinnell; "The Cowal Landslip," by Mr. W. R. Smellie; "The Pitchstone Dykes of South Arran," by Mr. Alex. Scott; "Carboniferous System of Scotland, East and West: A Palæontological Comparison," by Mr. John Smith; "The Lower Limestones in the Carboniferous Rocks of the Glasgow District," by Mr. P. Macnair and Mr. Conacher; "Notes on the Stornoway District of Lewis," by Mr.

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A. Stevens; "A Petrological Sketch of the Carrick Hills, Ayrshire," by Mr. G. W. Tyrrell; "The Fiords of Dalmatia and the Corries of Balglass," by Prof. J. W. Gregory, F.R.S. Most of the papers were followed by an animated discussion.

During the summer months sixteen excursions took place as follows. Some of these were well attended; others were but poorly so:—

Glen Croe, Arrochar. Mr. James L. Begg.
Kelvingrove Museum. Mr. Peter Macnair.
Kilwinning, Saltcoats. Mr. G. V. Wilson.
Hindog Glen, Dalry. Mr. John Smith.
Jock's Burn, Carluke. Mr. Harry R. J. Conacher.
Bathgate. Dr. J. D. Falconer.
Seedhill Clayfield, Paisley. Mr. Duncan Smith.
The Corries of Balglass. Prof. J. W. Gregory.
Inchinnan. Mr. James Steel.
Baldernock Linn, Milngavie. Mr. Harry R. J. Conacher.
Upper Greenock, Loch Thom, Skelmorlie. Mr. J. W. Reoch.
Robroyston Brickworks. Mr. Robert Dron.
Gryffe Water. Mr. Peter Macnair.
Eaglesham. Mr. George C. Watson.
Lugton and Uplaw Moor. Mr. D. Ferguson.
The Great Cumbrae. Mr. G. W. Tyrrell.

Among the losses due to death were Mr. Jas. Goldie, J.P., 52 St. Enoch Square, joined 1894; Mr. Arch. Hamilton, C.E., Clyde Navigation Office, joined 1872; Rev. A. Scott Mathieson, 7 Lynedoch Crescent, joined 1909; Mr. James A. Reid, LL.D. (of Macgregor & Donald), 172 St. Vincent Street, joined 1880; Wm. Sykes, 24 Hamilton Park Terrace, Hillhead, joined 1902; and Mr. Russell Frost Gwinnell, B.Sc., Assoc.R.C.Sci., F.G.S. Mr. Gwinnell was elected a Corresponding Member of the Society at the November meeting of last Session, and he died on the 15th March, 1913, at the early age of thirty-three. It will be remembered that he contributed a paper at that meeting on "An Occurrence of Dolomitic Limestone in Glen Fruin." He had been for some years Demonstrator in Geology under Prof. W. W. Watts, in the Imperial College of Science and Technology, South Kensington, and also an Examiner in Geology to the Board of Education. He constructed a relief model of a portion of the Scottish Highland Boundary, which was accompanied by an explanatory guide. He also constructed a similar model of Skye. The Rev. A. Scott Mathieson was only a member of the Society for about three years, but in that short time he took considerable interest in the welfare of the Society. He was a minister of the U.F. Church. He wrote upon science and religion. Some of his works are, "The Gospel and Modern Substitutes," "The Church and Social Problems," and "The City of Man." Mr. Goldie was Deacon Convener of the

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Trades House. He was well known in business circles in the city. His firm of James Goldie & Son, Limited, contractors, St. Enoch Square, has executed many notable public works and buildings in Glasgow. He was a Deputy Lieutenant of the county of the city of Glasgow, a manager of the Royal Infirmary, and a director of the Clyde Trust. Deceased, who was a native of Glasgow, was of a genial and kindly disposition, and was held in high respect by a wide circle of friends.

SOCIETY'S ROOMS, 207 BATH STREET, 9TH OCTOBER, 1913.

The first meeting of the fifty-sixth Session of the Geological Society of Glasgow was held here this evening—Dr. JOHN HORNE, F.R.S., in the chair.

The Minutes of the last meeting were read and adopted.

The Secretary (Mr. Macnair) read a letter from Mr. James W. Reoch, Joint Hon. Secretary, resigning that office, in which he wrote that, owing to the growing demands of business upon his spare time, he had found it, especially during last Session, increasingly difficult to discharge satisfactorily the duties of office as Joint Hon. Secretary to the Society, but while not desirous of holding any further office in the Society, he would be anxious to give what support he could as an ordinary member. The Secretary was instructed to write Mr. Reoch deeply regretting his inability to continue to hold office as Secretary, and thanking him for the many valuable services that he had rendered to the Society in the past.

Professor J. W. JUDD, C.B., F.R.S., then delivered the opening address, in which he said that "Continuity" was the subject of the address of the President of the British Association at its recent meeting in Birmingham, but the fact was often overlooked that the same term was made the basis of an address delivered forty-seven years ago from the same chair by another distinguished physicist. But while Sir Oliver Lodge used the term in a limited sense for continuity in space, Sir William Grove employed it with a much wider signification, not only for continuity in space but also for continuity in time, an idea now more usually expressed by the term "evolution." The doctrine of "continuity in time" (sometimes expressed by the cumbrous term "uniformitarianism") was now universally accepted by naturalists; and the fact that it was now so universally received was largely due to the labours of a number of illustrious Scottish geologists.

A vote of thanks to Prof. Judd for his most valuable and interesting address was proposed by Prof. GREGORY and seconded by Mr. C. R. COWIE.

G. W. TYRRELL.

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SOCIETY'S ROOMS, 207 BATH STREET, 13TH NOVEMBER, 1913.

The second meeting of the fifty-sixth Session of the Geological Society of Glasgow was held here this evening—Mr. G. W. TYRRELL, A.R.C.S., F.G.S., in the chair.

The Minutes of the last meeting were read and adopted.

The Annual Report of the Council for Session 1912-1913 was read by Mr. Peter Macnair, Hon. Secretary; the Financial Report by Mr. E. Hall Wight, the Treasurer; and the Library Report by Mr. Wm. Sinclair.

On the motion of Mr. JAMES NEILSON these were unanimously adopted.

The following office-bearers were elected:—

As Vice-President—Mr. James W. Reoch, proposed by Mr. John Renwick and Mr. Peter Macnair.

As Members of Council—Rev. Charles A. Hall, proposed by Mr. Wm. Sinclair and Mr. Duncan Smith; Mr. J. G. Roberts, proposed by Mr. Andrew Barclay and Mr. Harry R. J. Conacher; Mr. Murray MacGregor, M.A., B.Sc., proposed by Mr. W. R. Smellie and Mr. Alex. Stevens; Mr. Arch. Shanks, proposed by Mr E. Hall Wight and Mr. Wm. Sinclair.

The following were elected members:—

As Ordinary Members—Mr. Patrick Brough, Assistant Demonstrator, University, 50 Lawrence Street, Partick, proposed by Mr. W. R. Smellie and Mr. Alex. Stevens; Mr. David B. Duncanson, B.Sc. (Lond.), 19 King Edward Road, Jordanhill, proposed by Mr. Peter Macnair and Mr. Harry R. J. Conacher; Mr. John Barr, 53 Bothwell Street, Glasgow, proposed by Mr. Harry R. J. Conacher and Mr. Peter Macnair.

Dr. W. GEMMELL and Dr. R. M. BUCHANAN exhibited photographs and specimens from an oak tree which had been found during excavations at Fairfield Shipyard at a depth of 20 feet from the present surface level and midway between tidemarks. It seemed to be contemporaneous with the dug-out canoes which have been discovered from time to time in and around Glasgow. Considerable discussion took place as to the probable age of the deposits which contained these relics, their relationship to the raised beaches and to the glacial period.

Mr. MACNAIR exhibited vegetable remains from the same deposits at Greenock, where fragments of plants had been remarkably plentiful; and Mr. D. SMITH showed examples of the Post-Glacial shells from Seedhill, Paisley.

Mr. G. V. WILSON, H.M. Geological Survey, exhibited hand specimens and microscope sections of rocks from Mull containing sapphires and magnetite. The sapphires occur in a Tertiary shale, which has been so altered by contact with igneous rock that the sapphires have been developed as secondary minerals. This is the second such occur-

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rence of sapphires in Britain, the other instance being due to a similar action by the Ben Cruachan granite.

Mr. R. G. Carruthers, H.M. Geological Survey, exhibited a very fine slab containing shells of Posidonomya becheri from Dumfriesshire, which was interesting historically, as it was the first definite locality for the shell in Scotland. Generally the shell is a rare one, but when it does occur it is plentiful; in this instance it is confined to a bed about 1 inch thick, in the Lower Carboniferous Limestone group.

Mr. J. G. Roberts exhibited a very perfect specimen of Lima gigantea from the Lower Lias near Rugby, large crystals of celestine in several forms from a vertical vein near Bristol; Calamoclady's equisetiformis from the Staffordshire coalfield, and specimens of Carboniferous fishes from the same district.

Mr. C. R. Cowie showed specimens of flexible sandstone from Delhi, India; a number of specimens of jade or nephrite from North Burmah, both in the rough state and carved into various useful articles; also ambrite and specimens from the Burmese ruby mines. Ambrite resembles Baltic amber, but is chemically distinct. Mr. Cowie mentioned that recently when a number of tube wells were sunk in the streets of Mandalay the water brought up a considerable quantity of small rubies.

Mr. G. W. Tyrrell exhibited further specimens of flexible sandstone, and explained that it had been found that it owed its peculiar properties to the jointing together of its constituent grains in an unusual manner. He also showed specimens of various minerals from Greenock and Kilsyth.

Mr. G. C. Watson showed a large series of fossiliferous flints from Aberdeenshire, and explained that these fossils of chalk age are found over a district in which no Cretaceous rocks now exist *in situ*, and that they seem to be relics of beds which once overspread that area.

J. W. GREGORY.

Society's Rooms, 207 Bath Street, 11th December, 1913.

The third meeting of the fifty-sixth Session of the Geological Society of Glasgow was held here this evening—Professor J. W. Gregory, F.R.S., F.G.S., in the chair.

The Minutes of the last meeting were read and adopted.

Mr. J. L. Begg exhibited a very fine specimen of a ganoid fish from the Old Red Sandstone near Thurso. Mr. Begg pointed out the characteristics of the specimen, and explained that the scales, when first brought out from the rock, were of a dense black, but that they changed through exposure to air and light to a blue colour which

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varied in shade according to the length of time for which they had been exposed.

Mr. W. R. SMELLIE read a paper on "The Tertiary Composite Sill of South Bute." [See *Transactions*, p. 121.]

In the discussion which followed, Mr. TYRRELL suggested that some of the very peculiar features of the sill might be accounted for by supposing that gravitation had caused the separation of the magma into a heavier basic portion and a lighter acid part, and that when crystallisation commenced in the latter, the crystals, when formed, had sunk into the basic portion. Thus these would now be found in the dolerite minerals which properly belonged to the acid portion.

J. HORNE.

SOCIETY'S ROOMS, 207 BATH STREET, 8TH JANUARY, 1914.

The fourth meeting of the fifty-sixth Session of the Geological Society of Glasgow was held here this evening—Dr. J. HORNE, *President*, in the chair.

The Minutes of the last meeting were read and adopted.

The following were elected members:—

As Ordinary Members—Mr. A. J. Brown, 142 St. Vincent Street, Glasgow, proposed by Mr. R. W. Dron and Mr. Harry R. J. Conacher; Mr. Richard C. Farrell, A.M.I.C.E., 248 West George Street, Glasgow, proposed by Mr. Peter Macnair and Mr. Harry R. J. Conacher; Mr. Harry W. Lewin, 154 West Regent Street, Glasgow, proposed by Mr. Peter Macnair and Mr. Harry R. J. Conacher; Mr. J. R. Sutherland, M.Inst.C.E., City Chambers, Glasgow, proposed by Mr. Peter Macnair and Mr. Harry R. J. Conacher.

Mr. JOHN RENWICK moved that, in accordance with notice given at last meeting, £12 of the Society's funds be granted for Library purposes.

Mr. P. BROUGH, M.A., and Mr. JOHN V. HARRISON exhibited specimens of columnar sandstone from Kilchattan Bay, Bute. It was explained that the sandstone showing this peculiar structure occurred on the shores of Kilchattan Bay in a narrow strip running parallel to the igneous dykes of the district. The columns are roughly hexagonal, of varying size, and many are very cleanly formed. An examination of them shows that the constituent sand grains have been partially fused together so that only an occasional one shows its individual outline, and the rock resembles a quartzite. The characteristic red colour of the sandstone has also been discharged, and this has been found to be due to the alteration of the coating of hæmatite which normally envelops the grains. The spaces between the grains have been much diminished as compared to the normal. All these phenomena point to the columnar sandstone having been produced by the action of heat on the local red sandstone, and this is supported by the fact that similar columns can be produced in

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sandstone by heating it to somewhere below fusing point, and the size of the columns is proportional to the rate of cooling. It therefore seems probable that the columns in Kilchattan Bay are the visible evidence of the existence of an igneous dyke which has not yet been exposed to view by erosion.

Dr. HORNE congratulated the authors upon the lucid manner in which they had marshalled the evidence showing that the columnar structure was due to a dyke not exposed to view, and the Society in having young members who are able to produce such good work.

Dr. JOHN HORNE, *President* of the Society, delivered his presidential address on "The Canadian Shield." The address gave a brief account of some of the sections in the Canadian Shield, which were visited in the course of the transcontinental excursion (C1) between Toronto and Vancouver in connection with the International Geological Congress, held in Canada in 1913. The term, "Canadian Shield," was applied by Professor Suess to the enormous area of pre-Cambrian rocks, amounting to nearly 2,000,000 square miles, in the Dominion.

At the outset an outline was given of the development of research among the pre-Cambrian rocks of Canada since the time they were first studied by Sir William Logan in 1842. Reference was made to the various classifications of these rocks, which were presented to the Congress by American and Canadian geologists. At present no single classification holds the field, and the ultimate solution of the questions at issue must be left to future research. Hitherto certain areas of economic importance have been mapped and studied minutely, but the intervening districts require to be dealt with in a similar manner. When these intervening tracts are completed, further light would doubtless be thrown on these complicated problems.

The classification recommended by the joint committee of Canadian and United States Geological Surveys in 1904 is given in the subjoined table—

Cambrian.
Unconformity.
Pre-Cambrian.
Keweenawan (Nipigon).
Unconformity.
Huronian, - { **Upper (Animikie).** / *Unconformity.* / **Middle.** / *Unconformity.* / **Lower.**
Unconformity.
Keewatin.
Eruptive Contact.
Lawrentian.

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Van Hise and Leith have adopted a major grouping of formations in the above table. The Keweenawan and Huronian rocks are included by them in a great major division termed the Algonkian, while the Keewatin and Lawrentian divisions are classed with the Archæan. These investigators call attention to the magnitude of the unconformity between the Keewatin and Huronian rocks. According to the United States geologists, it is more conspicuous and more persistent over wide areas than any of the others.

Professor Lawson, on the other hand, has adopted the following classification, which gave rise to animated discussions during the Congress:—

Upper Cambrian (Potsdam).
Unconformity.
Algonkian, { Keweenawan (Nipigon).
Unconformity.
Animikie.

Eparchæan Interval.

Archæan, { Algoman (Granite-gneiss, batholitic in Huronian).
Irruptive Contact.
Huronian, { Upper.
Unconformity.
Lower.
Unconformity.
Lawrentian (Granite-gneiss, batholitic in Ontarian).
Irruptive Contact.
Ontarian, { Keewatin.
Contehiching.

The features of special importance in the above classification are (1) the inclusion of the Huronian rocks in the Archæan division; (2), the recognition of a set of plutonic rocks (Algoman) intrusive in the Huronian sub-divisions of Professor Lawson, and therefore later than the Lawrentian granite gneisses; (3) the restriction of the Algonkian major division to the Keweenawan and Animikie formations.

Professor Coleman and some of the officers of the Canadian Geological Survey adopt independent groupings of the pre-Cambrian rocks, which are also worthy of careful consideration.

In the classic region of the Rainy Lake and the Lake of the Woods, the Contehiching and Keewatin schists are clearly displayed. The former is a typical series of schists of sedimentary origin, resembling some of the metamorphic rocks of the Highlands of Scotland. On the shores of Rainy Lake these felspathic mica-schists are pierced by granite intrusions which have produced contact minerals in some of the bands. They are there thrown into gentle folds and pass underneath the Keewatin schists, the latter consisting mainly of basic and acid rocks of volcanic origin. Around the Lake of the

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Woods the pillow-structure assumed by the lavas of this series may be seen in various stages of deformation. Pyroclastic rocks are associated with the lavas. On the cliffs of the Winnipeg River below the point where it issues from the Lake of the Woods, the junction of the green chloritic and hornblende schists (Keewatin) with the Lawrentian granitoid gneisses is laid bare. Though the latter are intrusive in the former both groups are traversed by more or less parallel planes of foliation. From an economic point of view the Keewatin schists are of special importance, from the occurrence in them of valuable iron ores.

Special interest attached to the visit to the Steeprock Lake, where the Lower Huronian rocks are exposed. According to Professor Lawson's interpretation, these Lower Huronian strata form a steep synclinal fold, and rest, in some places, on a denuded platform of Lawrentian gneisses, and, in others, on the Keewatin schists. The beds dip at a high angle, and comprise, at the base, a thin schistose conglomerate merging into an arkose, followed by a zone of fossiliferous limestone, volcanic ash, and green schists, probably of detrital origin. The so-called fossils discovered by Professor Lawson in this limestone have been described by Dr. Walcott as intermediate forms related to the sponges, and named by him *Atikokania*.

The Seine series (Upper Huronian of Lawson and Middle Huronian of Van Hise and Leith) is separated by a marked unconformity from the Lawrentian and Keewatin rocks. Well marked conglomerates occur at intervals at the base, where pebbles vary according to the nature of the underlying floor. These graduate upwards into quartzites, slaty schists, and phyllites, the whole succession being comparatively unaltered except where the strata have been changed into mica-schists due to intrusions of Algoman granite.

Reference was made to sections of Animikie rocks near Port Arthur, comprising dark shales, slates, cherty dolomites and iron ores, the whole series resting unconformably on the Archæan floor. The striking feature of this division in that district is the presence of great sills of quartz-diabase with marked columnar jointing which form prominent features in the landscape.

The geological structure of the Sudbury region as worked out by Professor Coleman was briefly described. This region is famous for its valuable field of nickel ore, which occurs in association with a great sheet of intrusive igneous rock. The recent classification by Coleman is given below.

Post Keweenawan (?),	Dykes of diabase and granite.
Keweenawan (?),	Nickel-bearing eruptive sheet.
Huronian,	Upper—(Animikie), conglomerate, tuff, slate and sandstone.
	Middle—Not represented.
	Lower—Basal conglomerate.

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Lawrentian,	Granite and gneiss eruptive through older rocks.
Sudbury Series,	Copper Cliff arkrose, M'Kim greywacke, and Ramsay Lake quartzite.
Keewatin,	Iron formation, greenstones and green schists.
Grenville series,	Quartz, sillimanite schists and gneisses, and crystalline limestone.

The members of the Sudbury series, exposed at the town of Sudbury and to the south-east of that centre, are supposed to have been folded and extensively denuded before the deposition of the basal conglomerate (tillite) of Lower Huronian age, which rests on the upturned edges of the Ramsay Lake quartzite. This conglomerate is said to have been traced by Dr. Collins towards the north-east to the basal conglomerate at Cobalt, and by Dr. Coleman, at intervals, to the Lower Huronian conglomerate of the typical Huronian region to the west. If these observations are correct, then this zone may furnish an important link for correlating the strata in widely separated areas.

The great nickel-bearing eruptive sheet forms a syncline about 36 miles long by 17 miles wide, in the centre of which lie the Front Lake conglomerate, the Onaping tuff, the Onwatin slate, and the Chelmsford sandstone. The intrusive sheet is said to vary in thickness from half a mile to two miles. The lower portion of the sheet is composed of norite and the upper portion of micro-pegmatite. The nickel ore is scattered through the basal part of the norite, and solid bodies of ore occur at the outer or lower edge of the sheet. These relations are ascribed to magmatic differentiation, the more acid part of the magma rising to the top and the heavier portions sinking to the bottom. This view was first advanced by Professor Walker, of Toronto University, and has been strongly supported by the late Dr. Barlow and Professor Coleman.

J. W. GREGORY.

SOCIETY'S ROOMS, 207 BATH STREET, 12TH FEBRUARY, 1914.

The fifth meeting of the fifty-sixth Session of the Geological Society of Glasgow was held here this evening—Professor J. W. GREGORY, *Vice-President*, in the chair.

The Minutes of the last meeting were read and adopted.

The following were elected members:—

As Ordinary Member—Mr. James Milne, 15 Albion Street, Dowanhill, proposed by Mr. Peter Macnair and Mr. Harry R. J. Conacher.

As Associate Member—Mr. R. M. Chalmers, Tannochside, Uddingston, proposed by Mr. W. R. Smellie and Mr. P. Brough.

Mr. J. W. REOCH read, on behalf of Mr. ALEXANDER SCOTT, a

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paper on "A Composite Sill in Glen Cloy, Arran." [See *Transactions*, p. 140.]

In the discussion which followed, Professor GREGORY said this paper was an example of the results to be got by a combination of careful field work with a competent knowledge of physical chemistry. Mr. E. M. ANDERSON, H.M. Geological Survey, said he was much interested in Mr. Scott's results, because in mapping composite intrusives in Mull he had found marked differences from the features described in connection with the Arran occurrences.

Mr. R. G. CARRUTHERS, H.M. Geological Survey, read a paper on "The Carboniferous Sediments Around Strathaven." [See *Transactions*, p. 151.]

Mr. PETER MACNAIR and Mr. HARRY R. J. CONACHER read notes on "The Posidonomya Corrugata Index Bed in Ayrshire." The authors stated that this index bed, previously traced in Lennoxtown, Kilsyth, Carluke, and East Kilbride districts, had recently been found to hold good into North Ayrshire, where it existed in typical form in several localities. The practical utility of the bed, along with others more recently noted, in the work of correlating the strata over this wide district (extending for about 40 miles between extremes) was pointed out.

Mr. JAMES NEILSON agreed that there were marked similarities between the specimens exhibited from the various localities, but considered further evidence necessary before the authors' assumption would be justified.

Mr. R. G. CARRUTHERS, H.M. Geological Survey, said he had no doubt whatever as to the correctness of the identifications based on this index and the value of the bed as a "mark" for correlations, As already mentioned that evening, he had found it hold good at Strathaven.

Mr. RICHEY, H.M. Geological Survey, said that, while engaged in the revision of Ayrshire, he had found this index reliable and of great value. He had already found it as far south as Dalry, but in the area immediately north of Lugton, although the exact position for the bed was known, he had not found Posidonomya corrugata there.

J. W. REOCH.

SOCIETY'S ROOMS, 207 BATH STREET, 12TH MARCH, 1914.

The sixth meeting of the fifty-sixth Session of the Geological Society of Glasgow was held here this evening—Mr. J. W. REOCH, *Vice-President*, in the chair.

The following were elected members:—

As Ordinary Members—Mr. William Miller, 324 Cumbernauld Road, Dennistoun, proposed by Mr. Peter Macnair and Mr. Harry R. J.

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Conacher; Mr. William Howat, The Cottage, Motherwell, proposed by Mr. Peter Macnair and Mr. Harry R. J. Conacher; Mr. James Brown, 3 Victoria Terrace, Dullatur, proposed by Mr. Peter Macnair and Mr. Harry R. J. Conacher.

As Associate Members—Mr. William Feely, 127 Glebe Street, Glasgow, proposed by Mr. Peter Macnair and Mr. Harry R. J. Conacher; Mr. Patrick Austen, 57 Hamilton Street, Govan, proposed by Mr. William Sinclair and Mr. Harry R. J. Conacher; Mr. Leon Figdor, 34 Dunearn Street, Glasgow, proposed by Mr. William Sinclair and Mr. Harry R. J. Conacher; Mr. Alexander Wilson, 26 Westland Drive, Whiteinch, proposed by Mr. William Sinclair and Mr. Harry R. J. Conacher; Mr. David Biggart, Woodlands, Johnstone, proposed by Mr. William Sinclair and Mr. Harry R. J. Conacher.

Mr. JAMES WRIGHT, junior, and Mr. J. L. BEGG read "Notes on a Geological Visit to Gothland, Sweden," illustrated with lantern slides by Mr. Robert Dunlop, and an exhibit of specimens by Mr. James L. Begg, Mr. Robert Dunlop, and Mr. James Wright, junior.

The Island of Gothland consists of marl shales and overlying limestones, with an intervening series in the south, composed for the most part of sandstone. All are of Upper Silurian age, and their total thickness is considerably under 300 feet. No igneous phenomena in sill, trap, or dyke are to be seen in the whole island. The beds as a whole, having only a very gentle dip towards the south-east, the sequence of the lower as well as the higher members can be studied in detail at many places along the coast line and at sections in the interior.

On the shore north of Visby (the capital) the lowest beds of the island are seen to outcrop, viz., *Arachnophyllum* shale and *Stricklandinia* marl, which are probably the equivalent of the Upper Llandovery and Tarannon shales and sandstones of Britain.

Overlying these beds to north and south the marl shales of Wenlock age are seen, forming, as they do, a conspicuous feature in the under portion of the "Klintar," or cliffs.

These in turn are overlain by Reef and Crinoid Limestones, which have been subdivided into zones of *Pterygotus* Beds, Coral and Crinoid Conglomerate, *Leperditia* Shales, and Uppermost Cephalopod Limestone.

Since 1847, when Sir Roderick Murchison studied the Gothlandian formations and communicated his results to the Geological Society of London, considerable attention has been given to the rocks by such men as Angelin, Romer, Schmidt, Bather, and Lindström. Of these the last named commands special mention because his classification, with slight modifications, still holds the field.

Although our knowledge of the strata has greatly advanced since Murchison's time, especially in regard to the dip of the beds and the sequence of the strata in the south, still to him is due the credit

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not only of having made the formation known to British geologists, but also of having first correlated the Gothland rocks with our own Upper Silurian strata.

At the present time the Swedish Geological Survey are at work on the island, the northern part being surveyed by Dr. Hedstrom and the southern by Dr. Munthe. As a different system of nomenclature has been adopted by each of these geologists, it is difficult to connect the classification adopted for the opposite ends of the island and to follow the distribution of the beds over the whole island. It seems clear, however, that the lowest division, or Marl Shale group, and the uppermost, the Cephalopod Limestone, can be traced throughout, but the correlation of the intervening beds, which in the south comprise sandstone, oolite, and *Sphærocodium* beds, with those of the north, consisting of reef, stromatoporan and ostracod limestones, is not yet definitely known.

Dr. Munthe, who accompanied the party for two days in the east of the island, emphasises that, before we can thoroughly understand the sequence of the Gothland strata, we must have much further help from the palæontologists, and he gives an instance of the work of Professor Rothpletz, of Munich, on the Hydrozoa (*Sphærocodium*), &c., which play a great part in the Gothland strata, and are evidently of great stratigraphical importance.

With reference to the fossils collected, reference was made to the crinoids. Fourteen species were obtained, and of these four are either new or require further study. The collection of crinoids had been submitted to Dr. Bather, of the British Museum, at whose request the authors had presented to the museum the new and doubtful specimens. These, along with star-shaped structures which he had never seen before, but which are probably the summits of an interbrachial plate of a crinoid, will be described later by Dr. Bather.

Mr. DUNLOP, in referring to the fossils exhibited, said their special feature was their splendid preservation, which was in contrast with the state of affairs in Scottish strata of like age. Fossils are abundant at Girvan, but they are crushed and difficult to make out, while those of Gothland are fresh as if just dredged from the old Silurian bottom. He mentioned that the party had seen the striped glacial clays, described in Dr. Horne's address to the Society a year ago, on which De Geer has founded such valuable research, and that these clays could be matched with specimens from Garvel Dock, Greenock, and Inverkeithing, thus giving an opportunity for local workers to do for Scottish glacial geology what De Geer had done for Scandinavia.

The thanks and congratulations of the meeting were awarded to Messrs. Dunlop, Wright, and Begg.

G. W. TYRRELL.

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SOCIETY'S ROOMS, 207 BATH STREET, 9TH APRIL, 1914.

The seventh meeting of the fifty-sixth Session was held here this evening—Mr. G. W. TYRRELL, *Vice-President*, in the chair.

The Minutes of last meeting were read and adopted.

The following were elected members:—

As Ordinary Members—Mr. Matthew Brown, 48 West Regent Street, Glasgow, proposed by Mr. R. W. Dron and Mr. H. R. J. Conacher; Mr. John Brown, 78 Hill Street, Kilmarnock, proposed by Mr. C. T. Clough and Mr. E. M. Anderson; Mr. George Loudon Dunn, Annanhill, Kilmarnock, proposed by Mr. C. T. Clough and Mr. H. R. J. Conacher; Mr. David G. H. M'Queen, 7 Stewartville Gardens, Wishaw, proposed by Mr. David M'Creath and Mr. Wm. Boyd.

As Associate Member—Mr. Wm. Malloch, c/o Turner, 82 Marlborough Avenue, Broomhill, proposed by Mr. A. M'Lean and Mr. H. R. J. Conacher.

Mr. A. Macintyre and Mr. Alex. M'Lean were appointed Auditors for the current Session, on the proposal of Mr. E. H. Wight and Mr. H. R. J. Conacher.

Bailie SMITH exhibited a specimen of a star ruby which showed in a good light distinct signs of its internal crystalline structure, and he explained that this was a feature which, although not usually visible megascopically, formed an infallible test microscopically for distinguishing natural gems from artificial ones, which might be identical chemically and otherwise.

Mr. ROBERT DUNLOP gave an account of the recent explorations in Dura Den, Fife, in search of fossil fishes. He said that in the early days of geology no locality excited more interest than Dura Den. It was in 1827 that a student of St. Andrews University brought to Dr. Fleming a slab bearing some fish scales from a quarry in the neighbourhood, and in 1836 a mason called Dr. Anderson from a meeting of Presbytery to see a fossil fish which he had discovered in splitting a slab of sandstone from Dura Den. This commenced the keen search extending over many years, in which Hugh Miller, Sir Charles Lyell, Dr. Page, Sir Roderick Murchison, and others bore a part. In anticipation of the recent meeting of the British Association in Dundee arrangements were made by a local committee for the reopening of the bed to which the fish are practically confined, and the work produced such good results in 1912 that the British Association voted a sum for its continuance during the following year. Mr. Dunlop had been in charge of the operations, and exhibited a fine series of slides depicting the splendid specimens obtained, which have not yet been thoroughly examined. The fish were found to lie thickly within a small area, and different species occur side by side. The fish are of fresh water type, and their association with sun-cracked sandstone and marks of raindrops suggested that the animals

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had been killed by the drying up of the shallow water in which they lived. A curious feature was the absence of any other remains in addition to the fish, except a few signs of plants.

Mr. STARK said that it was no uncommon thing in the delta areas of India for low-lying country to be submerged alternately at different seasons by fresh and salt water, and that fish thus carried into shallow pools perished when the country resumed its normal aspect. He suggested that the Old Red Sandstone fish of Dura Den had been trapped in a similar way.

Reference was also made to the observed habit of some fish of burying themselves in mud on the approach of the dry season, having sufficient vitality to withstand desiccation, and then to release themselves on the return of the waters.

Mr. DUNLOP also read notes on the discovery of fossil chitons and other fossils in the Carboniferous formation of Fife. [See *Transactions*, p. 167.]

Mr. G. C. WATSON read notes on cretaceous fossils from the superficial deposits of Aberdeenshire. He said that in 1856 there was described to the Geological Society a series of fossils which had been collected from drifted materials in Aberdeenshire, and which seemed to indicate the occurrence of cretaceous rocks *in situ* at no great distance. Some of these fossils were preserved in flint, and were therefore referred to the chalk, while others were in fine sandstone recognised as Upper Greensand. Formerly both Upper and Lower Chalk forms and Upper Greensand species had been recognised, but it now appeared that Lower Greensand types were present also. The appearance of the material in which the fossils were found suggested that it had been drifted, but not far, and probably from the north. The flints were all water-rolled, and made up about 80 per cent. of the boulders in the local clay. The conditions accompanying the occurrence of these fossils had not been fully investigated, but Mr. Watson suggested that they represented the remains of Cretaceous strata which had once overlain the ancient rocks of the district, and that they had been preserved in an old drainage channel, thus accounting for the mixture of fossils from beds of different ages, the water-rolled fragments, and the immense blocks of sandstone.

J. W. GREGORY.

SOCIETY'S ROOMS, 207 BATH STREET, 14TH MAY, 1914.

The eighth meeting of the fifty-sixth Session was held here this evening—Professor J. W. GREGORY, *Vice-President*, in the chair.

The Minutes of last meeting were read and adopted.

Mr. H. Shaw Dunn, 2 Highburgh Terrace, Glasgow, was elected an Ordinary Member on the proposal of Mr. C. T. Clough and Mr. E. M. Anderson.

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Mr. P. MACNAIR read a paper on "The Hurlet Sequence in North Ayrshire." [See *Transactions*, p. 200.]

Mr. CARRUTHERS stated that he and Mr. Richey, on behalf of the Geological Survey, had been engaged on the same task as Mr. Macnair, but had come to quite different conclusions. For instance, Mr. Macnair's Hurlet Limestone in North Ayrshire was no more than a foot or so thick, whereas at Howwood—the nearest section outwith Ayrshire—it was 30 feet thick; he thought that too great a contrast, and Mr. Richey and he had taken the thick limestone of Dockra as the local representative of the Hurlet. They differed somewhat from Mr. Macnair in the reading of the Howwood section also, and Mr. Macnair had not taken into account the effect of the unconformity of the limestones on the lavas, which had been found to be an important factor. He laid on the table a paper setting forth the conclusions of himself and Mr. Richey. [See *Transactions*, p. 249.]

Mr. NEILSON considered that the identification of the Abden fish-bed with that of the Alum Shale and also the naming of some of the other fossils to be quite doubtful matters, and, in fact, questioned the value of the whole fauna of the Alum Shale for the purpose for which Mr. Macnair had used it.

Professor J. W. GREGORY read a paper on "The Red Sandstones of Arran." [See *Transactions*, p. 174.]

Mr. G. W. TYRRELL read a paper on "The Boundary between the Upper and Lower Divisions of the Red Rock Series near Whiting Bay and in the Sliddery Water, Arran." [See *Transactions*, p. 188.]

G. W. TYRRELL.

EXCURSIONS—1914

To Paduff Burn, Kilbirnie, on Saturday, 4th April—Mr. J. E. Richey, B.A.I. (H.M. Geological Survey), conductor. In the Burn an almost complete section is exposed through the Lower Carboniferous Limestone Series which comes above lavas of Calciferous Sandstone age. The upper beds consist chiefly of blaes with thin limestones, their development here being typical of North Ayrshire generally. They include the Johnstone Shell Bed and the Calderwood Cementstone. The lower part of the series is curtailed by overlap on to the Calciferous Sandstone lavas, but includes two thick limestones separated by ashy marls.

To Killin, on Monday, 13th April (Spring Holiday)—Mr. Peter Macnair, F.R.S.E., F.G.S., conductor. The object of the excursion was to examine the various schist zones exposed in the side of Craig-na-Cailleich to the north of Killin, including the Garnetiferous Schists, the Loch Tay Limestone, Ben Lawers Phyllites, and Quartzites. The structure of the great axial line of folding was seen in the stream

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section exposed on the side of the mountain. The glacial phenomena of the surrounding district were also explained.

To Saltcoats and Ardrossan Beach, on Saturday, 25th April—Mr. E. M. Anderson, M.A., B.Sc. (H.M. Geological Survey), conductor. The sections examined included Coal Measures, Millstone Grit volcanic series, Upper Limestone group, Lower Limestone group, Calciferous Sandstone volcanic series, and Upper Old Red Sandstone. Sills of picrite and teschenite, and numerous dolerite dykes, were also seen.

To Stonehouse and Strathaven, on Saturday, 9th May—Mr. R. G. Carruthers, F.G.S. (H.M. Geological Survey), conductor. The party walked from Stonehouse to Cot Castle, where sections of the Lower Limestone were examined, together with Upper Calciferous strata; the latter appear in a great cliff on the east bank in which there is a fine exposure of the Pendleside fossil bed discovered some years ago at Calderwood Glen, East Kilbride. On the west bank a Blackband Ironstone was seen, and, further up stream, excellent sections of the Main Limestone, &c. A visit was also paid to the Holeburn section, showing oil-shales and coal, together with a rich fossil bed, from which collections are easily made; these strata are of particular interest owing to their identification with various members of the Oil-Shale group of the Lothians.

To Crianlarich, on Tuesday, 19th May (King's Birthday)—Prof. J. W. Gregory, D.Sc., F.R.S., F.G.S., conductor. The object of this excursion was to examine the succession of rocks in the Loch Tay Series and its relation to the Ben Lawers Series. Ben nan Imirean, a peak 2769 feet high, is capped by a small outlier of the Ben Lawers Schist ("Phyllite"), which rests upon the Loch Tay Series. The section, during the walk from Crianlarich to Ben nan Imirean, exhibits an interesting succession of the varied rocks in the Loch Tay Series, including garnetiferous Mica-Schists, the Loch Tay Limestones, and a series of quartzites. These rocks to the south of Ben nan Imirean dip to the north; and to the north of it they dip to the south. The structure is therefore apparently a syncline. If so, the Loch Tay Series is older than the overlying Ben Lawers Schist, which is a true outlier. The only other available explanations are that the cap of Ben Lawers Schist is an inlier, or has been brought above the Loch Tay Series by overthrusting or overfolding. In the opinion of the leader of the excursion, the simple explanation that the Ben Lawers Schist is the younger rock is the most probable explanation.

To East Kilbride, on Saturday, 30th May—Mr. A. Stevens, M.A., conductor. Glacieluvial kaim with section in gravel pit showing bedding; lavas of Calciferous Sandstone age faulted against Carboniferous Limestone.

To Lennoxtown (Campsie Hills), on Saturday, 13th June—Mr. James W. Reoch, conductor. The party proceeded north from Lennoxtown and followed the Campsie Fault eastwards along the south face of the

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Campsie Fells, examining *en route* the various types of lavas and associated intrusives. Land-slipping phenomena were noticed, also occurrences of chalcedony in the lavas, as well as sections in the Lower Limestone Series.

To Glen Cloy, Arran, on Saturday, 20th June—Messrs. Charles R. Cowie and James W. Reoch, conductors. Glen Cloy is carved out along the strike of Lower Triasic sandstones and conglomerates, which dip generally to the south-east at 10 to 15 degrees. A Tertiary composite sill of felsite and pitchstone near Kilmichael (as lately described by Mr. A. Scott, junior), was examined at its exposure in the bed of the Cloy Burn, as well as various dykes, basic and acid, exposed in the glen. The diorites, granophyres, and felsites at the eastern edge of the Tertiary volcanic vent, and the associated Old Red Sandstone rocks, close around to form, at the head of the glen, a fine amphitheatre in which lies an alluvial flat, formerly the site of a loch dammed by moraines, through which the outlet burn has gradually cut until it has drained the loch. Amethystine quartz occurs at the head of the glen. Objects of archæological and historical interest were also pointed out.

To Nethercraigs, Paisley, on Wednesday, 23rd June (evening excursion)—Mr. Duncan Smith, conductor. The Nethercraigs strata consist of the Hurlet, Blackbyre, and Holybush Limestones, with their associated sediments, and they occupy a small syncline truncated to the south by the fault which brings up the lavas of the Fereneze Hills (*vide Transactions*, vol. xv., part I., page 39).

To Bathgate Hills, on Saturday, 12th September (joint excursion with the University Geological Society)—Mr. G. W. Tyrrell, A.R.C.Sc., F.G.S., conductor. The party visited the richly fossiliferous Petershill quarries in the Carboniferous Limestone Series, and thereafter the intercalated volcanic series, which consists largely of Dalmeny and Hillhouse basalts. The whole series is intersected by dykes and sills of quartz-dolerite.

To Kilmarnock, on Monday, 28th September (Autumn Holiday)—Mr. C. T. Clough, M.A. (H.M. Geological Survey), conductor. The object of the excursion was to examine sections of the Coal Measures in the Kilmarnock Water, Fenwick Water, and Craufurdland Water. The best exposures are in the lower part of the series, between the Hurlford Main Coal and the Kilwinning Main Coal. Important east and west faults cause some confusion, but by piecing together different parts of it, it is possible to make out the sequence between the two seams referred to with tolerable completeness. A considerable number of coal seams and "musselbands" are well exposed. The Millstone Grit Series, which in this district is largely represented by volcanic rocks, was also examined.

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ABSTRACT

OF THE

TREASURER'S ACCOUNTS.

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ABSTRACT OF THE TREASURER'S ACCOUNTS FOR THE YEAR ENDED 30TH SEPTEMBER, 1913.

CASH ACCOUNT.

RECEIPTS.

To Cash in Bank on Deposit,	£36 0 0	
,, Do. in Treasurer's hands,	2 19 1	
,, Do. Mr. C. R. Cowie's Donation,	1 12 11	
		£40 12 0
,, Subscriptions for current year (including 9 new Ordinary Members)—131 at 10/,		65 10 0
,, Do. 2 at 7/6,		0 15 0
,, Do. Arrears—3 at 10/,		1 10 0
,, Associate Members' Subscriptions—4 at 2/6,		0 10 0
,, *Transactions* Sold, including Jubilee Volume per Hon. Librarian,		5 5 9
,, Interest on Funds,		5 12 0
,, Do. Mr. C. R. Cowie's Donation,		3 5 11
		£123 0 8

EXPENDITURE.

By *Transactions*—			
,, Printing and Publishing Vol. XIV., Part 3, and for Reprints of Papers, £71 5/2, less receipts from Authors for extra copies of Re-prints, £2 8/5,	£68 16 9		
,, Postages and Outlays *re* do.,	0 19 6		
		£69 16 3	
,, Library—New Books and Bookbinding, Maps and Magazines,	£3 11 9		
,, Librarian's Outlays,	1 10 0		
,, Cabinet and Index Cards for Library,	2 4 0		
		7 5 9	
,, Printing and Postage of Circulars and Excursion Booklets, and Advertising,		18 9 10	
,, Rent, Insurance, and Attendance,		10 11 3	
,, Disbursements by Hon. Secretaries, Postages, Stationery, and Petty Expenses,		2 4 11	
,, Collector's Commission,		1 19 0	
,, Lantern Expenses,		2 6 3	
,, Subscription to Marine Biological Association, 1913,		1 1 0	
,, to Palæontographical Society, 1913,		1 1 0	
,, Mr. C. R. Cowie's Donation—			
Interest to Martinmas, 1912, paid to Glasgow University,	£1 12 11		
Do., to Royal Technical College, Glasgow,	1 12 11		
		3 5 10	
,, Cash in Bank on Deposit,	£3 0 0		
,, Do. in Treasurer's Hands,	0 6 7		
,, Do. Mr. C. R. Cowie's Donation,	1 13 0		
		4 19 7	
		£123 0 8	

LIFE SUBSCRIPTION ACCOUNT.

Sept. 30, 1913.—To Balance to Credit,		£177 5 0	September 30, 1912.—By Balance from last Account,	£177 5 0
		£177 5 0		£177 5 0

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ABSTRACT OF THE TREASURER'S ACCOUNTS FOR THE YEAR ENDED 30TH SEPTEMBER, 1913.

Mr. CHARLES R. COWIE'S DONATION.

Sept. 30, 1913.—To Glasgow University, one-half of Interest to Martinmas, 1912,		£1 12 11	Sept. 30, 1912.—By Balance from last Account,		£101 12 11
,, The Royal Technical College, Glasgow, one half of Interest to do.,		1 12 11	Sept. 30, 1913.— ,, One year's interest to Whitsunday, 1913,		3 5 11
Balance to Credit,		101 13 0			
		£104 18 10			£104 18 10

BALANCE SHEET.

To Life Subscription Account,		£177 5 0	By Invested with Campbeltown Corporation under Mortgage at 3½ per cent.,	£170 0 0	
,, Mr. Charles R. Cowie's Donation and accrued Interest,		101 13 0	,, Cash in Bank and in Hand,	3 6 7	
,, Capital Account,*		496 1 7			£173 6 7
			,, Property—Books in the Library,	£440 0 0	
			Furniture, Bookcases, & Microscope,	60 0 0	
					500 0 0
			,, Mr. Charles R. Cowie's Donation—Invested with Campbeltown Corporation under Mortgage at 3½ per cent.,	£100 0 0	
			,, Do., Interest accrued to Whitsunday, 1913,	1 13 0	
					101 13 0
		£774 19 7			£774 19 7

* NOTE.—Subject to cost of publishing *Transactions*.

GLASGOW, *5th November*, 1913.—Examined, compared with relative Vouchers and Securities, and found correct, the balance in Treasurer's hands being One Pound, Nineteen Shillings and Sevenpence; Six Shillings and Sevenpence being due to Society, and One Pound, Thirteen Shillings being Interest accrued on Mr. Charles R. Cowie's Donation.

D. PEARSON,
ARCH. MACINTYRE, } *Auditors.*

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THE GEOLOGICAL SOCIETY OF GLASGOW.

OFFICE-BEARERS FOR SESSION 1913-1914.

President—

Dr. JOHN HORNE, F.R.S., F.G.S.

Vice-Presidents—

Prof. J. W. GREGORY, D.Sc., F.R.S., F.G.S.
(*Retires*, 1914).

Mr. G. W. TYRRELL, A.R.C.Sc., F.G.S.
(*Retires* 1915).

Mr. J. W. REOCH.
(*Retires* 1916).

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Mr. R. W. DRON.	Mr. DUNCAN SMITH.	Mr. J. G. ROBERTS.
Dr. J. D. FALCONER.	Mr. P. A. LEITCH.	Mr. M. M'GREGOR.
Mr. WM. R. SMELLIE.	Mr. ANDREW C. KERR.	Mr. ARCH. SHANKS.

Honorary Secretaries—

Mr. PETER MACNAIR, F.R.S.E., F.G.S., Kelvingrove Museum.
Mr. H. R. J. CONACHER, Horsewood Road, Bridge-of-Weir.

Honorary Treasurer—

Mr. E. HALL WIGHT, 150 Hope Street.

Honorary Librarian—

Mr. WILLIAM SINCLAIR, 47 Oswald Street.

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Dr. John Horne, Professor J. W. Gregory, Messrs. E. Hall Wight, Charles R. Cowie, R. W. Dron, G. W. Tyrrell, Arch. A. Young; with P. Macnair, *Convener*.

Library Committee—

Messrs. James Steel, James Stark, James Anderson, Alex. M'Lean, P. Arthur Leitch, Wm. R. Smellie; with Wm. Sinclair, *Convener*.

Excursions Committee—

Professor J. W. Gregory, Messrs. John Renwick, G. W. Tyrrell, Andrew C. Kerr, Wm. R. Smellie, R. W. Dron, Dr. J. D. Falconer, M. M'Gregor, A. Stevens; with James L. Begg and Duncan Smith, *Joint Conveners*.

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1867. Woodward, Henry, LL.D., F.R.S., F.G.S., 13 Arundel Gardens, Notting Hill, London, W.

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1888. Teall, Dr. J. J. Harris, F.R.S., Museum of Practical Geology, Jermyn Street, London.

1900. Gray, Mrs. Robert, 59 George Street, Edinburgh.

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1902. Peach, B. N., LL.D., F.R.S., F.G.S., Geological Survey Office, Edinburgh.

1904. Jolly, Wm., F.R.S.E., Blantyre Lodge, Blantyre.

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1908. Bonney, Prof. T. G., Sc.D., LL.D., F.R.S., F.G.S., 9 Scroope Terrace, Cambridge.

1909. Smith, John, Dykes, Dalry, Ayrshire.

1909. Hind, Wheelton, M.D., B.S., F.R.C.S., Roxeth House, Stoke-on-Trent.

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1864. Mitchell, Rev. Hugh, LL.D., Craig, Montrose.
1867. Kerr, David, Wemyss Colliery, Fifeshire.
1871. Jack, R. L., LL.D., F.G.S., 36 Overstrand Mansions, Battersea Park, London.
1871. Jamieson, T. F., F.G.S., Ellon, Aberdeenshire.
1883. Scott, Thomas, F.L.S., Menzies Road, Torry, Aberdeenshire.
1884. Dobbie, J. J., M.A., D.Sc., Royal Scottish Museum, Edinburgh.
1884. Nathorst, Professor Alfred Gabriel, Stockholm, Sweden.
1898. Livingston, Colin, Ardtraigh, Fort-William.
1909. Young, James, Lesmahagow.

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1905. Anderson, E. M., M.A., B.Sc., H.M. Geological Survey Office, 33 George Square, Edinburgh.
1882. Anderson, James, 3 Herschell Street, Great Western Road, Glasgow.
1908. Anderson, P. J., M.A., LL.B., University Library, Aberdeen.
1912. Andrew, John, School House, Renton.

1898. Bain, James, The Whins, Alloa.
1911. Barclay, Andrew, F.E.I.S., Possilpark Public School, Possilpark.
1894.*Barr, Professor Archibald, Royston, Dowanhill, Glasgow.
1913. Barr, John, 53 Bothwell Street.
1893. Barr, Patrick, 51 Bath Street, Glasgow.
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1914. Borland, James, 8 Seaford Street, Kilmarnock.
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1913. Brough, Patrick, 50 Lawrence Street, Partick.
1914. Brown, A. J., 142 St. Vincent Street, Glasgow.
1909. Brown, George A., 35 Sunnyside Road, Coatbridge.
1914. Brown, James, 3 The Terrace, Dullatur, Dunbartonshire.
1914. Brown, John, 78 Hill Street, Kilmarnock.
1914. Brown, Matthew, 48 West Regent Street, Glasgow.
1904. Buchanan, R. M'Neil, M.B., C.M., F.F.P.S.G., Corindi, Scotstounhill, Glasgow.
1894. Burnett, John James, LL.D., A.R.S.A., 70 University Avenue, Hillhead, Glasgow.
1902. Burns, Professor Daniel, M.I.M.E., Technical College, George Street, Glasgow.

1907. Campbell, A. G., Artesian Works, Inchicore, Dublin.
1877. Campbell, John MacNaught, 6 Franklin Terrace, Sandyford.
1880. Carmichael, Robert S., Audit Office, St. Enoch Station, Glasgow.
1906. Carruthers, R. G., F.G.S., H.M. Geological Survey Office, 33 George Square, Edinburgh.
1895. Chalmers, David, 16 Berkeley Terrace, Glasgow.
1903. Clarkson, William Quarrymaster, Friar's Park, Lesmahagow.
1905.*Clough, C. T., M.A., H.M. Geological Survey Office, 33 George Square, Edinburgh.
1912. Conacher, Harry, R.J., Horsewood Road, Bridge of Weir.
1891. Cowie, Charles R., Woodend, Partickhill, Glasgow.
1900.*Cozens, Samuel F., Salem, Skelmorlie.
1907. Currie, Robert, A.G.T.C., M.I.M.E., 32 M'Lelland Drive, Kilmarnock.

1894. Dixon, Walter, Derwent, 30 Kelvinside Gardens, Kelvinside, Glasgow.
1907. Donald, W., The Eglinton Silica Brick Company, Ltd., Dundyvan, Coatbridge.
1881.*Dougan, John, 27 Smith Street, Hillhead, Glasgow.
1887. Dow, William, 17 Sommerville Drive, Mount Florida, Glasgow.

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1895. Dron, R. W., A.M.I.C.E., 55 West Regent Street, Glasgow.
1906. Drummond, John, Quarryhill Farm, Dunkeld, Blairgowrie.
1913. Duncanson, David B., B.Sc.(London), 19 King Edward Road, Jordanhill, Glasgow.
1883. Dunlop, Robert, Park Avenue, Dunfermline.
1914. Dunn, George Loudon, Annanhill, Kilmarnock.
1914. Dunn, H. Shaw, 2 Highburgh Terrace, Dowanhill, Glasgow.
1901. Du Toit, Alex. L., B.A., F.G.S., Geological Commission, South African Museum, Cape Town, S.A.

1901. Faill, John, 7 Winton Drive, Kelvinside, Glasgow.
1911. Falconer, Dr. J. D., M.A., F.G.S., F.R.S.E., Lecturer on Geography, The University, Glasgow.
1914. Farrell, Richard C., A.M.I.C.E., 248 West George Street, Glasgow.
1898. Fergus, A. Freeland, M.D., 22 Blythswood Square, Glasgow.
1906.*Ferguson, Professor, M.A., LL.D., 13 Newton Place, Glasgow.
1898.*French, Thomas, 1 Kelvinside Terrace, Kelvinside, Glasgow.

1901. Gale, William M., C.E., 1 Athole Gardens Place, Kelvinside, Glasgow.
1887. Gardner, John, 65 Great Clyde Street, Glasgow.
1901. Gemmell, E. W., Ettrick Mount, Libberton, Midlothian.
1912. Gilchrist, Percy C., 3 Claremont Gardens, Milngavie.
1894.*Gilfillan, William, 185 St. Vincent Street, Glasgow.
1908. Gilmour, Matthew B., Saffronhall House, Hamilton.
1873.*Gilmour, Thomas, M.D., Port Ellen, Islay.
1895. Glen, Alexander, 25 Dumbreck Road, Glasgow.
1877.*Graham, M. M., 21 Bath Street, Glasgow.
1904.*Gregory, Professor John Walter, D.Sc., F.R.S., F.G.S., Professor of Geology, Glasgow University.

1907. Hall, Rev. Charles A., Meersbrook, Meikleriggs, Paisley.
1908. Hendry, David, Dunmore, Thomson Avenue, Johnstone.

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1912. Herdsman, W. H., 144 Wellington Street, Glasgow.

1903. Hill, Alexander, 11 Dolphin Road, Pollokshields, Glasgow.

1877. Hislop, George R., F.C.S., F.R.S.E., Greenhill House, Paisley.

1891. Hodge, William, 27 Montgomerie Drive, Kelvinside, Glasgow.

1897. Houston, Robert S., Meadowside, Glasgow Road, Paisley.

1914. Howat, William, The Cottage, Motherwell.

1894. Hubbard, Walter Raglan, 9 Broomhill Avenue, Partick, Glasgow.

1908. Hunter, George, M.I.M.E., Mining Department, University, Glasgow.

1901. Hunter, William, Rosemount, Ledard Road, Langside, Glasgow.

1903. Hurll, Mark, Redholm, Temple.

1911. *Innes, Peter, 5 Ibrox Place, Paisley Road, West, Glasgow.

1912. Jack, Thomas, Blackhall, Brookfield, Johnstone.

1901. Kemp, William, c/o Mrs. Brown, 1 Doune Quadrant, Kelvinside North, Glasgow.

1908. Kerr, Andrew C., c/o Carron Company, 125 Buchanan Street, Glasgow.

1908. Kerr, David, Lynnewood, 140 Bo'ness Road, Grangemouth.

1890. Kidston, Robert, LL.D., F.R.S., 12 Clarendon Place, Stirling.

1882. King, Hugh B., Solicitor, Kilwinning.

1882. King, Robert C., Solicitor, Ledcameroch, Kilwinning.

1908. *Knight, James, M.A., D.Sc., F.R.S.E., F.G.S., F.C.S., St. James's Public School, Calton, Glasgow.

1883. Laird, Andrew, C.E., 137 West Regent Street, Glasgow.

1908. Leitch, P. Arthur, Engineer's Office, District Offices, Hamilton.

1914. Lewin, Harry W., Civil and Mining Engineer, 154 West Regent Street, Glasgow.

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1910. M'Callum, Gavin W., 208 Kilmarnock Road, Glasgow.
1912. Macaulay, James, Broughallan Gardens, Kirn.
1896. M'Cowan, Donald, Dundashill House, Port-Dundas, Glasgow.
1889. M'Creath, George W., M.E., 208 St. Vincent Street, Glasgow.
1904. M'Creath, William, C.E., M.I.M.E., 208 St. Vincent Street, Glasgow.
1901. M'Culloch, Andrew, 11 West Regent Street, Glasgow.
1884. M'Donald, A. B., C.E., 64 Cochrane Street, Glasgow.
1908. M'Donald, David P., M.A., B.Sc., S. A. School of Mines and Technology, Johannesburg.
1898. M'Gavin, Alex., 10 Lothian Gardens, Kelvinside North, Glasgow.
1894.*M'Gilvray, Robert A., 17 Annfield Road, Partickhill, Glasgow.
1867. M'Glashan, John, 114 Candleriggs, Glasgow.
1910. M'Gregor, Murray, M.A., B.Sc., H.M. Geological Survey, 33 George Square, Edinburgh.
1904. Macintyre, Arch., F.S.A.A., Muirbrow Chambers, Hamilton.
1894. Mackie, John, M.E., Crofthead Cottage, Neilston.
1877. Maclay, Bailie William, F.G.S., Thornwood Hall, Langside.
1894. Maclay, James, M.A., LL.B., Ferndean, Garelochhead.
1903. M'Lean, Alexander, 466 St. George's Road, Glasgow.
1895. Macnair, Peter, F.R.S.E., F.G.S., Art Galleries and Museum, Kelvingrove, Glasgow.
1897.*M'Neil, Charles, 1 University Gardens, Glasgow.
1910. MacPhee, Miss Margt. F., Broompark, Helensburgh.
1914. M'Queen, David P. H., 7 Stewartville Gardens, Wishaw.
1883. M'Whirr, John, J.P., 3 St. John's Road, Cathcart, Glasgow.
1887. Main, John, F.G.S., 24 Marlborough Avenue, Partick.
1900. Mann, Andrew C., 30 Lansdowne Crescent, Glasgow.
1874. Mann, Ludovic M'Lellan, F.S.A.(Scot.), 144 St. Vincent Street, Glasgow.
1902. Menzies, James R., 72 Lauderdale Gardens, Hyndland, Glasgow.

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1914. Milne, James, 15 Albion Street, Dowanhill, Glasgow.
1881. Mitchell, G. A., 5 West Regent Street, Glasgow.
1904. Moore, Quintin, Garrowbank House, Riddrie.
1877. Moore, Robert T., D.Sc., C.E., 142 St. Vincent Street, Glasgow.
1908.*Morrison, James, 87 East Princes Street, Helensburgh.
1889. Motherwell, A. B., Rosemount, Airdrie.
1900.*Muirhead, John, 13 St. John's Drive, Pollokshields, Glasgow.
1898. Munro, Alexander, 63 Lauderdale Gardens, Hyndland, Glasgow.
1894.*Murdoch, Robert, 91 Maxwell Road, Pollokshields, Glasgow.
1907.*Murdoch, J. A. W., Capelrig, Dunblane.
1870.*Murray, David, LL.D., 169 West George Street, Glasgow.
1907. Murray, Andrew G., c/o Brownlie, Watson & Beckett, 225 West George Street, Glasgow.

1907. Neilson, Miss Agnes T., 41 West Cumberland Street, Glasgow.
1891. Neilson, James, Alma Boiler Works, Crownpoint Road, Glasgow.
1894.*Neilson, James, 116 Bishop Street, Port-Dundas, Glasgow.
1907. Nicol, J. Hall, Builder and Contractor, Hamilton.
1898. Nimmo, David, 17 Duke Street, Hamilton.

1869.*Orr, John, 12 Newhall Terrace, Glasgow.

1891. Pollok, Arthur, Kirkland, Bonhill, Dunbartonshire.
1910. Preston, Frank A. B., 16 Waverley Park, Shawlands, Glasgow.
1910. Priestly, H., 8 Glenview, Paisley.

1873. Rankine, David, C.E., 238 West George Street, Glasgow.
1874. Renwick, John, 47 Oswald Street, Glasgow.
1902. Reoch, James W., 22 Montgomerie Street, Kelvinside.
1911. Roberts, J. G., Trees Cottage, Barrhead.
1875.*Rottenburg, Paul, LL.D., Holmhurst, Dowanhill Gardens, Glasgow.

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Year of Election.

1912. Scott, Alexander, jun., M.A., B.Sc., 137 St. Andrew's Road, Pollokshields, Glasgow.

1897. Shanks, Arch., 5 Green Lodge Terrace, Greenhead, Glasgow.

1893.*Sharp, John Grant, 127 Great Hamilton Street, Glasgow.

1910. Shute, Arthur E., 4 Holyrood Crescent West, Glasgow.

1887. Sinclair, William, 47 Oswald Street, Glasgow.

1889. Sloan, Samuel, M.D., 5 Somerset Place, Sauchiehall Street, Glasgow.

1911. Smellie, Wm. R., M.A., B.Sc., Mayfield Villa, Mossend.

1908. Smith Duncan, Laurelbank, Arkleston Road, Paisley.

1912. Smith, John, 34 Causeyside Street, Paisley.

1887.*Somerville, Rev. James E., B.D., Castellar, Crieff.

1871.*Sommerville, Joseph, 40 Montgomerie Street, Kelvinside North, Glasgow.

1902. Spencer, James S., 14 University Gardens, Glasgow.

1896. Stark, James, 13 Princes Gardens, Partick, Glasgow.

1881. Steel, James, 37 Prince Edward Street, Crosshill, Glasgow.

1912. Stevens, Alexander, M.A., Students' Settlement, 10 Possil Road, Glasgow.

1906. Stewart, Robert D., Ardgowan Villa, Bowling Green Road, Shettleston, Glasgow.

1878. Stewart, Thomas, St. George's Chambers, Cape Town, South Africa.

1911. Stewart, W. Wylie, 312 West Princes Street, Glasgow.

1891. Stirling, David, 10 Cook Street, Glasgow.

1914. Sutherland, J.R., M.Inst.C.E., Engineer's Office, 45 John Street, Glasgow.

1909. Tervet, G. Macleod, 9 Whitehaugh Drive, Paisley.

1897. Thomson, Henry, 10 Princes Square, Strathbungo, Glasgow.

1906. Tyrrell, G. W., A.R.C.Sc., F.G.S., Geological Department, Glasgow University.

1907. Waddell, A. W., M.E., 4 Eton Terrace, Hillhead, Glasgow.

1912. Walker, James Grahame, Glencairn, Alder Road, Hillpark, Glasgow.

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Year of Election.

1910. Watson, George C., 65 Chapel Street, Maryhill, Glasgow.

1901. Wight, E. Hall, 150 Hope Street, Glasgow.

1909. Williamson, James, A.M.I.C.E., 160 Hope Street, Glasgow.

1909. Wise, Thomas, Blackwood, Miller Street, Hamilton.

1912. Wordie, James M., 52 Montgomerie Drive, Glasgow.

1881. Wotherspoon, David, 1108 Argyle Street, Glasgow.

1910. Wright, James, 36 Douglas Street, Kirkcaldy.

1911. Wyllie, B. K. N., M.A., c/o Secretariat, Geological Survey, Accra, Gold Coast.

1902. Young, Arch. A., 2 Parkgrove Terrace West, Glasgow.

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TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY OF GLASGOW.

No. XVIII.—The Age of Loch Long, and its Relation to the Valley System of Southern Scotland.

By Professor J. W. Gregory, F.R.S., D.Sc.

[Read 14th January, 1915; issued separately 25th February, 1915.]

I. The Origin of the Valley System of the Loch Long District.

Loch Long has been often called a fiord, and is the most typical fiord in south-western Scotland. It is easy of access, being traversed by the West Highland Railway, and it affords an excellent test case as to the extent to which the valleys of this part of Scotland have been deepened and their hanging valleys have been caused by glacial excavation. The mouth of the hanging valley of Coilessan Glen is a little over 500 feet above Loch Long, which is there 30 fathoms deep. This difference of level is attributed by one theory to the glacial deepening of the main valley to the extent of about 700 feet. There is, however, an alternative explanation, according to which Loch Long lies in a pre-glacial valley that need not have been much deepened by glacial excavation. This explanation was briefly stated in my work on Fiords (1913, p. 437), but as no illustrations or details of Loch Long were there given it may be as well to state the evidence.

The origin of the valley system to which Loch Long belongs was first explained in a most suggestive paper by Mr. Cadell in

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1886.[1] To understand the origin of these valleys it is necessary to consider the geographical condition of western Scotland in early Kainozoic times. During the Eocene or Oligocene Periods —the evidence, though uncertain, appears to indicate the latter date—the Western Isles of Scotland were a field of great volcanic activity. After the eruptions the volcanic area probably sank; but before these subsidences the level of western Scotland must have been higher than it is now, and from this high land many rivers flowed south-eastward. As Mr. Cadell remarked, the valleys on the site of Loch Goil and its continuation, the Gareloch, of Glen Croe and the Tarbet gap, and of Loch Eck with the Holy Loch, were probably excavated by rivers flowing from the north-west into the Clyde Valley.

The First Valley System.—Between Crianlarich and Dunoon there are nine valleys which may be included in this original system (Pl. XXXI.). These valleys are in order the Dubh Eas-Glengyle, Glen Sloy-Loch Arklet, Glen Croe and the Tarbet gap, Coilessan Glen continued by Glen Douglas,[2] Glen Luss, Glen Fruin, the valley of Lochgoil and the Gareloch, Glen Finnart and the lower reach of Loch Long, and, finally, Loch Eck and the Holy Loch.

Dubh Eas, which rises in the high ground near Ben Lui, would have been continued across Glen Falloch into Allt Innse; thence, up the tributary of the Innse to the south-west of Parland Hill, it would have crossed the windgap into Glen Gyle, and thus passed to Loch Katrine. This stream would have received as tributaries on its south-western bank the Allt Arnan and the Dubh Uisge. The valleys of the Dubh Eas, Allt Arnan, and the Dubh Uisge converge toward the mouth of the Allt Innse, on the eastern side of Glen Falloch. The lower Allt Innse follows the direction of Dubh Eas to the pass leading to Glen Gyle. The river in Glen Sloy, the Inveruglas, was probably joined by the two streams from Allt Coiregrogain that now discharge through Glen Loin to Loch Long; but the

[1] Further details are given in Mr. Cadell's "The Story of the Forth" (1913, pp. 56-80); except for some secondary points, his conclusions regarding the rivers from Glen Sloy southward are the same as those adopted in this paper.

[2] The former continuation of these two glens was suggested by Cadell, who says that they are "exactly in line" (Cadell, 1886, p, 346).

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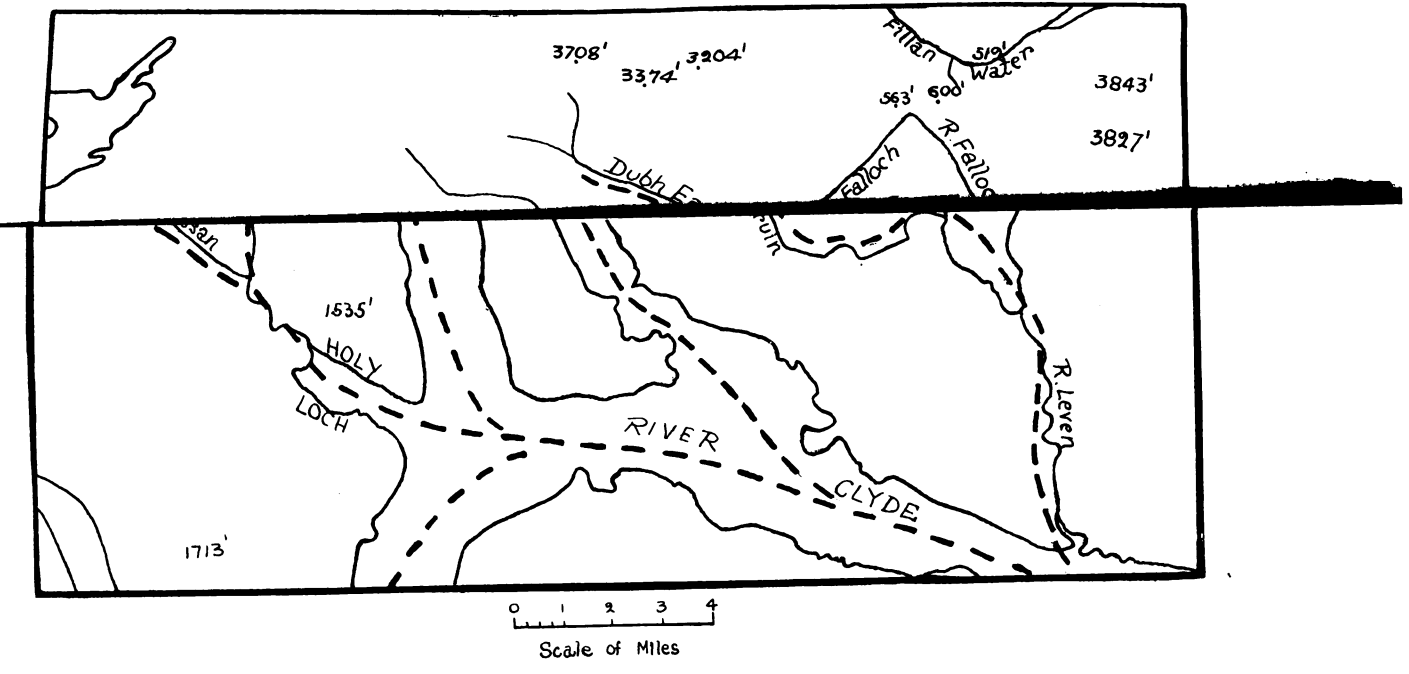

Sketch Map of the Loch Long District.

- - - - - The probable course of the valleys which date from the primitive Lower Kainozoic river system.

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Inveruglas probably originally crossed the site of Loch Lomond, and passed through the hanging valley at Inversnaid to Loch Arklet, and thus to Loch Katrine.

Glen Croe, as suggested by Cadell, once continued through the Tarbet gap, towards which the U-shaped section of the glen above Larachpark points directly. The trend of the Tarbet gap to the north of east and of the south-eastern face of Cruach Tarbet, above the contour of 600 feet, to the north-east may both be due to the course of the Glencroe-Tarbet river when it joined the Inveruglas and discharged through the Loch Arklet gap.

The stream from Coilessan Glen doubtless at the same time continued down Glen Douglas, and, turning to the south, was joined by the Luss and Fruin Waters, and flowed into the Clyde. The next of this series of streams ran through Hell's Glen to the Gareloch. It has now been subdivided, for Hell's Glen has been left as a hanging valley by the deepening of Allt Glinne Mhoir, and Loch Goil has been separated from the Gareloch by the extension of the outer reach of Loch Long. That part of Loch Long was probably initiated as the lower end of Glen Finnart. The most southern of this series of valleys is that of the Holy Loch and Loch Eck, which is continued to Loch Fyne over the deeply cut windgap at Strachur.

Level of the Old Valleys.—The courses suggested for these rivers were only possible so long as the levels were higher on the western than on the eastern side of the Lomond-Falloch Valley. The hanging valley of Dubh Eas now ends at the height of between 550 and 600 feet, whereas the mouth of the hanging valley on the opposite side is at about 700 feet, and the pass at its head, the Glengyle windgap, is at the height of a little below 1500 feet. The peaks around the head of Glen Eas, however, rise to heights of from 2400 to 3700 feet, and that glen has been cut in a plateau which was not less than 2400 feet high and that height was sufficient to have given the original Dubh Eas an outlet across the Glengyle windgap. As soon as the Falloch Valley opposite Dubh Eas was lowered beneath the 1500-feet contour the stream must have found another outlet, and this was probably at first north-eastward over Crianlarich

to the valley of the Dochart.[3] Similarly, the Glen Croe and Glen Loin rivers can only have discharged through Loch Arklet when their beds were above the level of 470 feet. The whole of the Loch Long district was a high plateau, the level of which was over 2000 feet from Glen Falloch to Glen Fruin and the Holy Loch; and to the south of the two last glens it was at the height of over 1700 feet—the height still reached by the Renfrewshire Hills (1711 feet) and by the hills (1713 feet) west of Dunoon.

The Oligocene Valleys were cut into this high plateau; the beds of the valleys were therefore originally not less than 1700 feet above present sea-level. The denudation of the subsequent valleys of Loch Long and Loch Lomond was, however, probably accomplished in Pliocene times, when the land stood at a much higher level. This uplift is generally accepted[4] in order to explain the platform at the height of from 800 to 1000 feet, for which there is abundant evidence throughout Scotland. If the country then stood so much above present sea-level, the formation of the inner basin of Loch Long, which sinks 180 feet below O.D., and even the northern basin of Loch Lomond, which is over 600 feet deep, might have been due to river erosion.

II. Extension of the Valleys across Loch Fyne and to the Tweed.

Mr. Cadell traced this river system north-westward as far as the south-eastern side of Loch Fyne, where he placed the original watershed; but the principle on which his conclusions were founded admits of the further extension of these rivers in both directions. The south-eastern side of the Loch Fyne Valley is notched by windgaps between Strachur and Loch Eck at the level of only 186 feet, at the head of Hell's Glen at 727 feet, and between Kinglas and Glen Croe at 860 feet. The depths of these three notches beneath the adjacent peaks are respectively 800, 1300, and 2100 feet.

[3] I am glad to find that Messrs. A. Scott and B. K. N. Wyllie have independently come to the conclusion that Dubh Uisge once discharged to Glen Dochart.

[4] This is the Intermediate Plateau of Peach and Horne (1910, in Murray and Pullar, vol. i., p. 458).

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The Strachur gap was probably cut by a river flowing across the site of Loch Fyne, and that river must have been due to the junction of those in Glens Aray and Shira. These three windgaps show that the watershed was once further to the north-west in the mountains of the Lorne district.

The Oligocene rivers may also be traced to the south-east of the Clyde Valley. Mr. Cadell's paper deals with a period when the drainage from the Dumbartonshire Highlands passed eastward through the Kelvin and the Forth into the Firth of Forth. The view that the drainage was originally in that direction has two great recommendations. First, the Forth is the largest estuary on the eastern coast, so that it may appear reasonable to conclude that its excavation required the longest time, so that the Forth would be the oldest river valley in southern Scotland. Second, according to this view, the drainage would be confined to the Midland Valley of Scotland, and no outlet would be required across the Southern Uplands. The argument, from the size of the estuary, would also indicate the great antiquity of the lower Clyde; and Drs. Peach and Horne (1910, pp. 445-6) attribute the Midland Valley to a prolonged struggle between the Clyde and Forth, during which the watershed oscillated eastward and westward.

In addition to the hypotheses of Cadell and of Peach and Horne, there is a third. Sir Archibald Geikie pointed out in his "Scenery of Scotland" (1st edition, 1865, p. 288; 3rd edition, 1901, p. 378), from the existence of the Biggar gap, that the Clyde had possibly once been the upper part of the Tweed. Mr. Mackinder (1902, pp.132-3) has developed this view, and regards the Tweed as the lower end of a river which rose in the mountains of Argyll. In spite of its boldness, this theory seems to me probably correct.

The evidence for this view is the existence of a series of windgaps through the Southern Uplands. Windgaps are not necessarily made by rivers flowing right through the mountain range, for the cutting back of an escarpment produces windgaps at the heads of the ordinary valleys of the dip slope. The gap at Strachur cannot, however, be attributed to the recession of an escarpment, and the general relations of the windgaps beside Loch Fyne and through the Southern Uplands indicate that

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those gaps were cut by antecedent rivers which flowed across the country from north-west to south-east.

The windgaps through the Southern Uplands include that at Biggar, about 660 feet, which almost connects the Clyde and the Tweed. To the south-west of this gap the Southern Uplands are intersected by the Beattock Pass (1029 feet) between the Upper Clyde and the Annan; by the gap of New Cumnock (650 feet), which is at the head of the Nith, and is used by the Glasgow and South-Western Railway; and by that between Loch Doon and the Water of Ken, at a little below 780 feet.

The Biggar gap was probably cut when the Clyde continued south-eastward along the valley of the Tweed. This can, of course, only have happened when the floor of the Lower Clyde Valley was above the level of the Biggar gap. The distance from that gap to Dumbarton is about 46 miles. From the Biggar gap to the mouth of the Tweed the present valley has a fall of about 8 feet in the mile. But in Oligocene times the land probably extended further eastward, and the fall per mile was probably less. The size of the Biggar gap shows that it was cut by a considerable river, and the fall of the valley from Dumbarton to Biggar may have been as low as 2 feet in the mile. But if we assume a fall of 8 feet to the mile, and thus continue the present grade of the Tweed Valley from Biggar to the Lower Clyde, the old Clyde-Tweed River about Dumbarton would have been at the height of about 1000 feet above present sea-level. The remains of an old plain there at about that level may be remnants of the floor of this ancient valley.

The escape of the Clyde through its present estuary was at first prevented by the greater elevation and size of Arran. The nucleus of northern Arran is a massif of granitic rocks, which were intruded at about the same period as the volcanic eruptions of the Western Isles; and there can be no doubt from the structure of Arran that the island was once much higher and larger, and that it would have formed a complete barrier between the Glasgow district and the sea to the south of Arran.

III. The Disruption of the Clyde-Tweed River.

The hypothesis that the Clyde once began in Argyll and ended as the Tweed is not inconsistent with the views of Messrs.

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Peach, Horne, and Cadell. It refers to a stage prior to those *considered* in Cadell's paper, and before the struggle between the Clyde and Forth. This Clyde-Tweed River must have been broken up at an early date, for the Upper Tweed is at a higher level than the Lower Clyde, and has a narrower valley. The Tweed probably soon lost its north-western headstreams, owing to the Forth and the Kelvin cutting their way westward along the softer Carboniferous rocks; and this process was perhaps aided by renewed earth movements, since, according to Bailey (1910, p. 10), the Midland Valley is a rift-valley. The drainage of the Dumbartonshire Highlands probably for a time passed to the Forth. This stage was reached at latest when the Clyde, near Dumbarton, had cut its valley down to the level of about 700 feet, for it would then no longer have had sufficient fall to deepen the Biggar gap.

The Clyde-Tweed was thus succeeded by the Lower Clyde-Kelvin-Forth, and this was in turn broken up by the opening of the outlet throughout the Clyde estuary past Arran.

Meanwhile the tributary streams would have been enlarging their valleys, and especially those that lay along lines of weakness, such as Loch Fyne along a band of easily weathered schists, and Loch Long, the Upper Glen Falloch, and Loch Lomond along fault planes. The formation of a subsequent valley along Loch Long would then have diverted the drainage of Loch Goil, Coilessan Glen, Glen Croe, and Glen Loin from the Loch Lomond Valley to the Clyde estuary. Glens Douglas and Luss were thus beheaded, and so appear from Loch Long as hanging valleys. Coilessan Glen and Ant Sreaag, just south of the Tarbet gap, are typical hanging valleys.

The varying height of the windgap suggests, as Mr. Cadell has remarked (1913, p. 68), the progress in the development of these subsequent valleys. Thus the drainage from the Loch Long valley probably discharged by the Tarbet gap (145 feet) for some time after Glen Douglas (508 feet) had been beheaded; and at a later stage the cutting through of the hard rocks north of Whistlefield joined the upper and lower parts of the Loch Long Valley.

About the same time denudation along the Loch Lomond fault would have diverted all the western drainage and that from the Falloch southward to the Clyde.

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IV. The Pre-Glacial Age of Loch Long.

This hypothesis of the origin of Loch Long assumes that the erosion of the subsequent valleys was due to river action in pre-Glacial times. The essential point in reference to the extent of glacial excavation in this part of Scotland is whether these valleys were excavated in pre-Glacial or in Glacial times. That the notches have been lowered to some extent by ice flowing over them is probable; but at each of these gaps the floor is irregular and hummocked, and not planed down to a smooth, even surface. The floor is moutonné—not nivelé, to use Whymper's phrase; and this fact indicates that the amount of glacial deepening at the windgaps has been slight.

The evidence against the formation of these valleys by glacial erosion is as follows:—

(a) *The Trend of the Valleys.*—Loch Long and its tributary valleys have not the trend that would be expected if they had been cut by the ice-sheet that flowed over this district. The direction of movement of the ice is shown on the maps of the Geological Survey and in its memoir on Cowal. These maps represent the main movement of the ice across the higher ridges as from north-west to south-east; and that this was the general movement is obvious from the form of the hills between Loch Long and Loch Lomond. After the ice-sheet had dwindled into glaciers, they naturally flowed along the valleys, and thus many of the lower striations are parallel to the valleys. Mr. Cadell has previously accepted the Tarbet gap as due to pre-Glacial river action by a prolongation of the Glen Croe river. He remarks, the Tarbet gap "lies right across the path of the glaciers during the Ice Age, and could not consequently have been eroded by them" (Cadell, 1886, p. 346).

The glaciers moved along lines pre-determined by the form of the ground.

(b) *The Shape of Glen Croe.*—It will probably be universally admitted that the valleys were initiated in pre-Glacial times, and the question is whether the ice materially deepened or only moulded the pre-Glacial valleys. The claim that the valleys were not greatly deepened by glacial agency is based on evidence that some of them had been cut to their present depth

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in pre-Glacial times. Glen Croe is the most easily accessible of the valleys which illustrate this feature. It is near Arrochar, and a good view of it can be obtained from the West Highland Railway above Ardmay. The spurs on the higher hillsides above the valley show evidence of having been worn by ice flowing down the glen. Nevertheless, as shown by Mr. Reoch's photographs (Plate XXXII., Figs. 1 and 2), taken looking up the

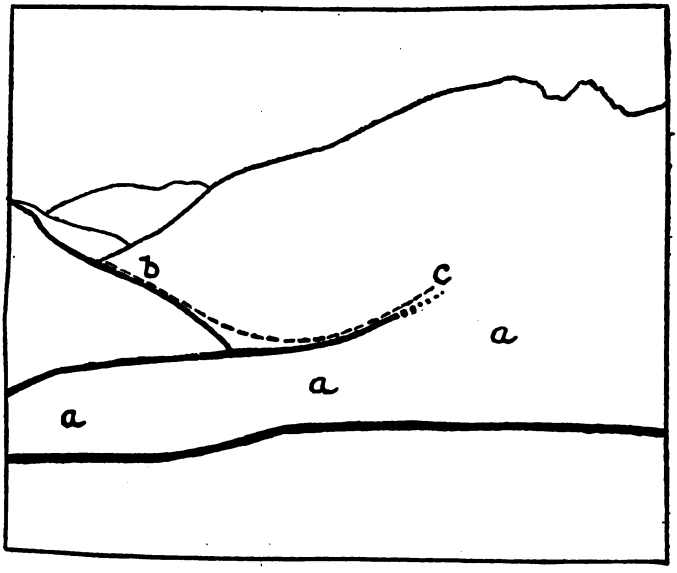

Fig. 1.—Diagram to illustrate section of Plate XXXII., Fig. 2.

aaa.—Glaciated spur which ends, as seen in Fig. 2, at the road to the west of Ardgartan Cottage, the conspicuous white building.

bc.—Floor of the U-shaped section of Glen Croe due to the free ice flow down the glen above Larachpark over the lower end of the spur *a*.

glen, the lower part is sinuous; the profiles from the two sides overlap, so that there is no clear view up the glen. The bottom of the glen for half a mile above its mouth retains the characteristics of a river-cut gorge.[5] It is certainly not post-Glacial, for striated and ice-worn surfaces occur on its floor.

[5] "Glen Croe," says Mr. Cadell (1913, p. 59), "is very deep and narrow."

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Glen Croe consists of four parts—(1) The uppermost part extends for almost 2 miles, trending south-eastward, from "Rest and be Thankful" (860 feet), and includes High Glencroe; it ends at the level of about 350 feet, just below the 17th milestone; this part of the glen is a straight, U-shaped, typically glaciated valley, with a clean-swept floor. (2) Below the 17th milestone the glen bends to the east, and the floor becomes irregular, as it is strewn with moraines; their preservation shows that this part of the glen cannot have been appreciably deepened by post-Glacial corrosion. Just below the 18th milestone the river has cut a post-Glacial channel on the floor of the valley, which descends steeply by a rock step. The roches moutonnées above this step show that even there the ice did not fully wear down the irregularities in the rocks beneath it, though the spurs on the side of the valley were cut back. (3) At the foot of this step begins the third part of the glen, which, like the first part, is a U-shaped, smooth-floored, glaciated valley; it extends for about three-quarters of a mile, trends east, and ends at Larachpark at the level of about 150 feet. (4) The last part is the mouth of the glen; it is half a mile long, and trends south-eastward. The bottom of the glen is narrow, and retains its pre-Glacial river-cut V shape.

The difference between the upper sections of the glen and the part near its mouth may be explained by the ice on the floor of the last having remained comparatively stagnant, while the ice above it flowed freely down the valley. The ice above the level of 200 feet discharged freely through the broad upper section of the mouth of Glen Croe. But the ice below the level of about 170 feet lay in a narrow, sinuous gorge, and would therefore have remained comparatively stagnant. The overlapping profiles on the bottom of lower Glen Croe show that the glen must have been cut to its present depth, *i.e.*, to existing sea-level, in pre-Glacial times.

When I first saw Glen Croe from the Highland Railway I thought it was partly post-Glacial, and made an early excursion to it in the expectation of finding an instance of extensive post-Glacial erosion. On this excursion a clearer view from the railway lessened this anticipation, and I was not surprised when I reached the glen to find along its floor numerous glaciated

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surfaces, which show that the lower glen is not post-Glacial (Fig. 2).

Glaciated surfaces occur in the meadow to the south-west of Ardgartan Cottage, at the height of 50 feet. They also occur on the river bank beside the same meadow, above and below a footbridge (not shown on the 6-inch map), at the height of 15

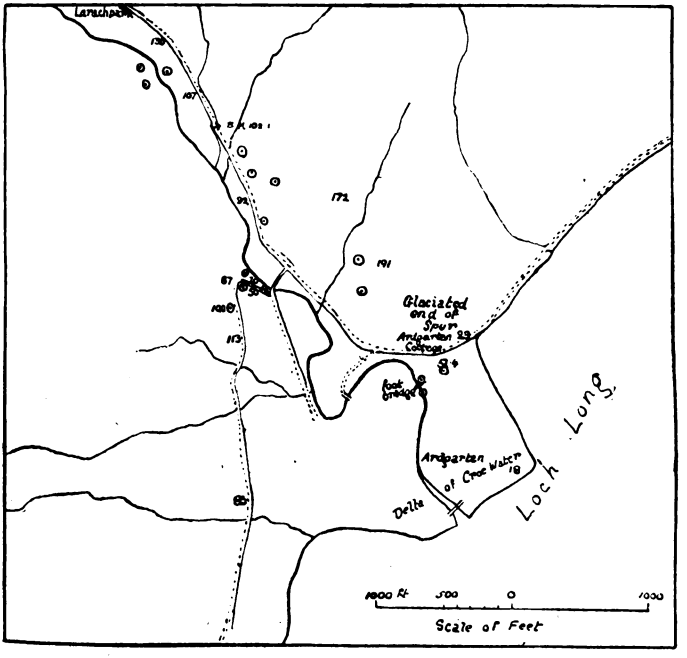

Fig. 2.—Sketch Map of the Mouth of Glen Croe showing the glaciated surfaces. Heights in feet.

feet. These exposures have been water-worn, but still show the form of roches moutonnées, which is especially conspicuous in two bosses to the north of the footbridge. Glaciated surfaces occur along the northern side of the road just west of Ardgartan Cottage, and extend down to 47 feet. These are at the end of the glaciated rock spur between Glen Croe and Loch Long, and may have been caused by ice flowing down Loch Long, but glaciated surfaces occur low down on the Glen Croe side.

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Further up Glen Croe, on the right bank, glaciated surfaces occur at the height of 100 feet and of 125 feet on the western edge of the wood west of the north lodge of Ardgartan. They occur at 70 feet in the wood beside the Glen Croe Water, north-west of the bridge opposite the north lodge; and a surface, which, though water-worn, is probably glaciated, occurs at the river-side there at 50 feet. Glaciated surfaces also occur on the eastern side of the main road at the height of about 100 feet at the rocks marked on the 6-inch map 70 yards south-south-east from the bench mark 102·1 feet. At about the same level there are glaciated surfaces on both banks of the river above and below the point opposite where 107 feet is marked on the road in the 6-inch map.

The valley of Glen Croe was certainly glaciated at levels varying from 100 feet to below 50 feet, and to as low as 15 feet at the mouth of the glen. Post-Glacial erosion has been limited to the denudation of the moraines and to the cutting of a rock trench from 2 to 8 feet deep on the present bed of the Croe Water.

From the head of Glen Croe the valley of the Allt Glinne Mhoir descends south-westward to Lochgoilhead. It is a deep V-shaped valley, with steep sides and a sinuous course, and its spurs overlap. It shows perhaps best of all the valleys of this district the characteristics of a pre-Glacial river gorge, for the ice that occupied it moulded the upper part of the section, but left the glen with its V shape and river-cut features.

(c) *Midhill Glen.*—Another striking illustration of these unmodified pre-Glacial valleys is the tributary to the Douglas Water between the eastern end of Doune Hill and Mid Hill. From the head of this valley there is a windgap to Glen Mallochan at the height of about 700 feet. The glen itself is narrow, deep, and sinuous. That it was occupied by ice is shown by the moraines within it; but the ice did not plane away the spurs, and thus convert this river gorge into the form of a glaciated valley. The fact that the glacier had so little effect on this glen was doubtless due to its situation across the line of the ice flow; hence the ice in it must have been almost stagnant, while ice streams were flowing past its two ends down Glen Douglas and Glen Mallochan; and when an ice-sheet covered the whole

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country, the ice passed freely across that imprisoned in the glen. The floor of this glen descended in pre-Glacial times from 700 feet at its head to 300 feet at its mouth. The ice has therefore done very little to deepen either Glen Douglas or the windgap at its head.

If the Tarbet Gap, Midhill Glen, Glinne Mhoir (Lochgoilhead), and Glen Croe had been cut to their present depths in pre-Glacial times, the valleys into which they led were necessarily also pre-Glacial.

(d) *Minor Hanging Valleys due to Lateral Erosion.*—The passage of the glacier through Loch Long has helped to straighten its course by wearing away the lateral spurs, and this process has left some pre-Glacial tributaries as hanging valleys. This process may be illustrated by three examples. The ice for a time pressed heavily against the south-eastern side of Loch Long south of Arrochar, and the bank there was rubbed back into a straight, spurless slope. The spurs on each side of Ant Sreaag were worn away, and the lower course of the glen was steepened. Most of Ant Sreaag is therefore a hanging valley, as is well seen from the opposite shore of Loch Long. A second type occurs 5 miles further down Loch Long. There the straight course of the loch is interrupted by the projection from the north-western shore of the promontory of Feoileann. This headland is due to an occurrence of unusually hard rocks, which resisted denudation and directed the flow of the ice against the south-eastern bank. This bank was therefore worn back, forming the area of low ground near Glenmallan and Ardarroch. Gleann Culanach and the stream south of Tom Buidhe that reaches the loch north of Ardarroch both had their lower courses worn backward, and are left as hanging valleys. This process involved some lateral erosion below the 300-feet level. A third case is on the western bank of the loch above Blairmore, where the widening of the lower section of Loch Long left a hanging valley, with its mouth at the level of over 200 feet. The formation of these minor hanging valleys involves only local lateral erosion where ice was directed against the valley sides with special power. They involve no deepening of the Loch Long valley.

(e) *Evidence of the Buried Pre-Glacial Channel of the Kelvin.*

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—These valleys then appear to prove that Loch Long had been cut down to present sea-level in pre-Glacial times. Whether the basin below sea-level, 30 fathoms deep, was also pre-Glacial there is no direct evidence available. But that even the drowned part of the Loch Long valley was mainly or wholly pre-Glacial is rendered probable by the existence of still deeper pre-Glacial valleys beside the Lower Clyde. That the Kelvin River had a deep pre-Glacial channel has been well known since the valuable paper by Bennie (1868). This buried channel is 240 feet below sea-level at Drumry, and, if its floor continues to descend at the same rate, it must be over 300 feet below O.D. south of Duntocher. Its depth further west under the present Clyde Valley between Bowling and Dumbarton is unknown. This buried valley has been filled up by glacial deposits, but its form and relations to the shallower pre-Glacial Clyde show that it was river-cut. Mr. Carruthers' valuable sketch map (1911, plate at end) of the pre-Glacial valleys near Glasgow shows that that of the Kelvin was deeper than that of the Clyde. The Clyde is represented as a hanging valley on the left bank of the Kelvin, which was therefore the older river. Both these channels were doubtless excavated during the Pliocene uplift, and were filled during the pre-Glacial and Glacial subsidence.

Mr. Cadell represents this pre-Glacial Kelvin as having flowed eastward to the Forth; but as the valley deepens from 170 feet below O.D. near Cadder to 240 feet below O.D. 6½ miles to the west, it must at least in its later period have belonged to a river flowing westward. If the Kelvin had cut its valley 240 feet below O.D. near Glasgow, it would be strange if the rivers which joined the Clyde estuary had not also cut their valleys below sea-level. If the Loch Long River had excavated its valley to a corresponding depth to that of the Kelvin, the full depth of the Loch Long basin would be pre-Glacial.

(f) *General Conclusions.*—Just before the glaciation of Scotland the submerged basin of Loch Long was already in existence, Glen Croe had been excavated to sea-level, and Coilessan Glen had been left as a hanging valley owing to its severance from Glen Douglas. When the Glacial period began Loch Long would have been a mountain gorge with hanging valleys left beside it, owing to corrosion having been more rapid by the

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main river than by the tributary streams. The district would have been in a condition of topographic immaturity owing to the Pliocene uplift. This condition is the most favourable for the erosion of lateral spurs, so that most of the sinuous valleys were straightened, the ridge crests lowered, and the mountain summits rounded by glacial denudation. These effects of glaciation are well illustrated in the Loch Long valleys, which appear, however, to have been deepened by glacial excavation only to a very slight extent.

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EXPLANATION OF PLATE XXXII.

PLATE I., FIGS. 1 and 2.—Two photographs looking up Glen Croe from across Loch Long, by J. W. Reoch, Esq.

FIG. 1.—Shows the smooth glaciated crest of the spur between lower Glen Croe and Loch Long, with three overlapping spurs behind.

FIG. 2.—The glaciated spur ends to the left at the road; the trees to the left of the road are on the delta deposits. The U form of the glen above Larachpark can be recognised from the left bank.

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Fig. 1.

Fig. 2.

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No. XIX.—The Girvan Landslip.

By J. V. Harrison, B.Sc., Baxter Demonstrator in Geology, Glasgow University.

[Read 11th March, 1915; issued separately 10th February, 1916.]

On the last day of 1914, after an extended period of heavy rain, a small landslip occurred 5 miles south of Girvan. The topography of this district is determined by the geological structure, for the steep hills rising from the sea depend fairly closely on the dip slope of the underlying Ordovician lavas and conglomerates. The coast is rugged and set with stacks and buttresses. Upon this solid foundation lies an ample mantle of boulder clay, with a steep face overhanging the road.

A portion of this clay had fallen, and moved bodily, with its covering of turf, across the road running from Girvan to Ballantrae, blocking it with débris for 30 yards to a depth of about 5 feet. Above this material a small lakelet had been formed by the runnels from the scar, and on the raised beach beneath there was a fan of deposition. Some of the clay involved in the fall had taken up a wavelike form, the crests and troughs being concentric, and parallel to the edge of the scar.

The cause of this landslide was a better lubrication, and hence a diminution of cohesion, along a plane of weakness in the clay. Such planes usually exist in boulder clay, their extent and distribution, however, being most erratic, and due to sandy layers in the clay. No sand was observed in the scar near Girvan, as it had been deluged with rain before examination was possible. For such a slide to take place $\beta < \omega$ is the necessary condition, where β is the angle of inclination of the plane of weakness, and ω the angle of repose.[1] It is necessary to assume the presence of a sandy layer, as water could readily flow along this, and render the clay on each side of it a slurry, for it is not until this state is reached that the tenacity of saturated clay is appreciably lessened.[2]

1 A. Penck, "Morphologie der Erdoberfläche," Erste Teil., 1894, pp. 222-224.

2 A. B. Searle, "Natural History of Clay," 1913, p. 151.

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The Girvan landslip falls into Heim's classification[3] as a "soilslip" or "earthslide." It is a true landslide, exhibiting many of the features which, when developed on the large scale, do so much damage; *e.g.*, the slipping away of a mass of rock *en bloc*, and the formation of earth-dammed lakes. The characters displayed here form an interesting contrast to those exhibited in the Cowal "landslip,"[4] which was the result of greatly increased powers of stream transport.

The wave-like ridges set up in the débris are seen in many other landslides,[5] an especially good series being developed in the landfall at Rosebery Topping, near Guisborough, Yorkshire. Here half a hill has fallen away, leaving a cliff 300 feet high. The material affected is upper Liassic Sandstone, which is lying flat, and the *débacle* is due to the removal of the underlying Cleveland Ironstone.

This structure is due to bedded rocks, including clay, having a greater resistance to crushing than to tensile forces, a feature which is often greatly intensified by jointing. When a mass of such material is set in motion down a slope the anterior portions are retained in movement by the mass behind, whilst the posterior portions have nothing to counteract any tendency to stop which they might display. The result of this, together with the small tensile strength, is the arrangement of the hinder rocks in parallel ridges.

3 Quoted by E. Howe, "Landslides in the San Juan Mts.," Prof. Pap., 67, *U.S. Geol. Surv.*, 1909, p. 41.

4 W. R. Smellie, "The Cowal Landslip." *Trans. Geol. Soc. Glasgow.* Vol. xiv., Pt. I., 1912, pp. 9-15.

5 A. Penck, Op. cit., p. 228.

I. C. Russell, "Topographic Features Due to Landslides," *Pop. Sci. Monthly.* Vol. 53, 1898, p. 485.

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No. XX.—Notes on the Geology of the East Kilsyth Hills.

By John V. Harrison, B.Sc., Baxter Demonstrator in Geology, Glasgow University.

[Read 11th March, 1915; issued separately 10th February, 1916.]

I. Introduction.
II. Topography and Surface Deposits.
III. The Relations of the Igneous Rocks.
IV. Petrography.
V. Petrology.
VI. Summary.

I. Introduction.

During an excursion across the Kilsyth Hills, the large development of tuff cut by dykes led Professor Gregory to suggest that the area might yield some interesting results on detailed study. The portion of country considered is that lying to the east of a line drawn from the Laird's Loup, on the Garrel Burn, to Burnhouse Farm, and to the west of the Takmedoon Road. The River Carron forms the northern boundary, and the fault separating the lavas and sandstones from the Carboniferous Limestone Series, the southern. The country to the east, north, and west is a continuation of the plateau lavas, but to the south the sediments extend.

II. Topography and Surface Deposits.

From Drumtocher, three-quarters of a mile north of Kilsyth, the steep southern face of the Kilsyth Hills appears to be composed of a series of lavas dipping gently to the east. The approach to the hills is over a steadily rising but gentle slope, covered by thick boulder clay, through which solid rock is only exposed in the deep trenches cut by the Garrel and Greenbank Burns and their tributaries. Above this the lavas rise in an imperfect arrangement of terraces, so characteristic of the Kilpatrick Hills.[1] The effect of this inclination of the lavas

1 G. W. Tyrrell, "Petrology of the Kilpatrick Hills." *Trans. Geol. Soc., Glasgow*, vol. xiv., pt. iii., p. 220. 1912.

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is at once apparent on the drainage, as on each of the terraces is a morass with an outlet to the east, which accounts for the trend of the streams rising near the summit on the south, *e.g.*, the Greenbank. This burn and its tributaries flow for a time parallel to the axis of the high ground, and not normal to it. The summit is clad by a small development of peat.

The different nature of the northern side is apparent when viewed from the Denny-Fintry Road near Craigannet Farm. A gradual slope, unbroken by escarpments, rises from the River Carron to the skyline, and a development of boulder clay terraces is well marked. Each of these so nearly maintains a constant level as to suggest that the series was deposited in lakes. That intra-morainic lakes did exist is emphasised by the occurrence of dry, overflow channels,[2] or "slacks." The first of these occurs at the highest level just south of Drumbouy, a second somewhat lower between Drumbouy and Cock Hill (both of which have a general E.N.E. trend), and a third small one near the foot of the March Burn.

A small terminal moraine, the deposit from a local glacier which lay in the hollow between Garrel and Hunt Hills, is cut by the March Burn, and a series of well-developed lateral moraines,[3] prominent near Waterside and Craigannet Farms, lies in the Carron valley. On the west side of Faughlin Reservoir a well-shaped morainic mound is situated, probably deposited by the glacier lying in the hollow down which the road passes.

Two stretches of alluvium, representing the beds of lakes formed near the end of glacial times, fall within the area. The first of these is the large, flat tract, "Loch Carron," extending to the south of the Denny-Fintry Road, finally drained by the Carron cutting its deep gorge to the east. The second, a much smaller one, was dammed by a large drumlin about three-quarters of a mile from the junction of the March Burn with the Carron. This lake was probably drained before the complete recession of the ice from the Craigannet part of the valley, by two streams working round the ends of the obstructing clay.

2 E. B. Bailey, "Geology of the Glasgow District." *Memoir Geol. Sur.*, p. 188. 1911.

3 J. W. Gregory. *Proc. Geol. Assoc.* Vol. xxvi., p. 160. 1915.

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III. The Relations of the Igneous Rocks.

The components of Garrel Hill, Tomtain, and Drumbouy are in the main badly exposed on the north, and, although often partially obscured on the south, are more clearly seen there. The Garrel Burn section, with its succession of tuffs and lavas, has been fully described by Mr. Lothian,[4] and is also mentioned in the Survey Memoir.[5] It is remarkable for exposing the most basic rock in the whole area, viz., a Craiglockhart basalt, which occurs at the lowest horizon of all the extrusives. Close to the Laird's Loup a thin dyke cuts the flow which causes the waterfall. Six flows are exposed one above the other in the southern face of Garrel Hill, each being a fairly porphyritic Markle basalt. Sparse augite crystals are sometimes found along with the abundant felspar. The flat-topped platform, Little Hill, is made up of two flows of a similar type, and the same rock composes Tomtain. Here there is a very considerable degree of variability in the profusion of phenocrysts, some flows being rich and others poor. A good exposure of ash is seen where the Greenbank Burn cascades over a prominent lava scarp about half a mile west of the road. This ash is red and greenish white, with a dip of 10° N. From the Takmedoon Road another section through the same hill may be seen, which is of some interest, since near Berryhill Farm a lava occurs interstratified with the sandstones of Calciferous Sandstone Age. The main mass of the lavas rests directly on the shales and cement-stones close to this farm. All the rocks exposed from here to Faughlin Reservoir, on the northern slopes of the hills, are strongly porphyritic Markle basalts.

Of the burn sections to the north, that in the March Burn is at once the most complete and interesting. Starting in the west there is an abundance of Jedburgh basalts, with occasional thin ash beds cut by a few bostonite dykes. The highest flow occurring in the westmost stream is a micro-Dunsapie basalt. In Braesburn several fine-grained basalts are under-

4 A. V. Lothian, "Petrology of the Kilsyth Hills," p. 18. 1902.
5 E. B. Bailey, *loc. cit.*, pp. 99-100.

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lain by a single flow of Markle, which is persistent along a part of the southern shore of "Loch Carron."

The March Burn splits into several branches at about the 900 feet contour line, and the westmost of these yields an intermittent section up to the hilltop, where there is visible the Markle cap resting on the fine-grained types below. In the March Burn, starting at the moraine near its source, two flows of Markle basalt are first encountered, separated by a thin bed of tuff. This tuff thickens out as the lower lava thins, so that it seems clear that the lower flow ended where it is now seen and was covered by a thick layer of ash, which removed the surface irregularities introduced by the first flow. The younger flow was then extruded, preserving the wedge-shaped intercalation of tuff from removal. The details of the section are as follows:—

Local Moraine.
150 yds. Boulder clay.
150 yds. Markle basalt.
1 yd. Thin ash.
20 yds. Markle basalt.
55 yds. Ash.
66 yds. Quartz dolerite dyke (E.W.) with chilled edges and spheroidal weathering.
4 yds. Bostonite dyke.
50 yds. Markle basalt.
16 yds. Ash.
½ yd. Dalmeny basalt, dyke or boulder in agglomerate.
85 yds. Ash.
2 yds. Andesitic mugearite, E.W. dyke.
5 yds. Vesicular basaltic-mugearite, E.W. dyke.
160 yds. Ash and alluvium, with one thin basalt dyke.
20 yds. Vesicular bostonite intrusion.
2 yds. Ash.
550 yds. Alluvium of old intra-morainic lake.
200 yds. Boulder clay.
120 yds. Jedburgh basalt.
100 yds. Markle basalt.

In a small burn just to the west, none of this tuff is present, but at a corresponding altitude only Jedburgh basalt occurs. To the east, however, several small streams show ash extending in that direction, cut as usual by dykes and associated with agglomerate, and one of them enters the alluvium through a gateway cut in a Markle basalt dyke. Further up this stream, a fall about 25 feet high is caused by a mass of hard agglomerate resisting the cutting power of the water. This plug contains

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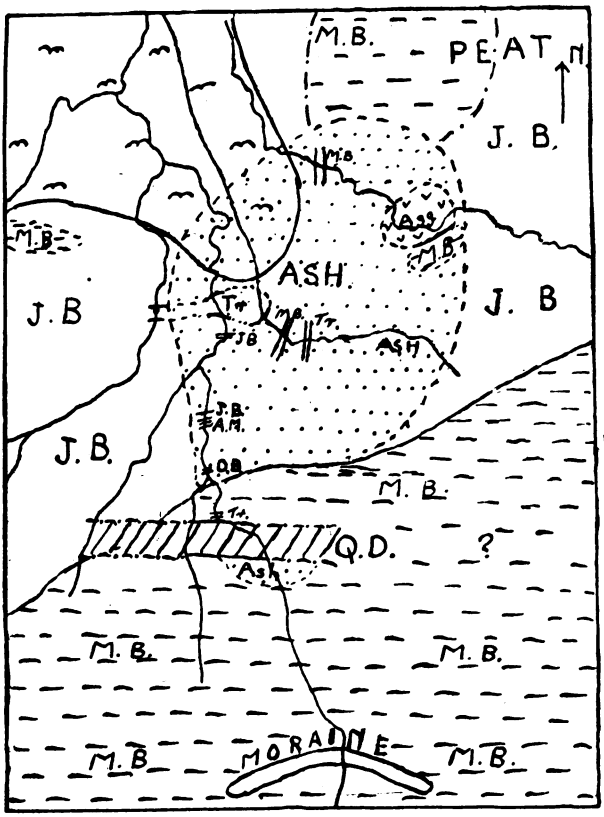

SCALE 0 1/8 MI. 1/4 MI. 3/8 MI.

0 100 200 300 400 500 FT.

MAP OF THE MARCH BURN

ALLUVIUM; O.R M.B. MARKLE BASALT:.

J.B. JEDBURGH BASALT D.B. _____ DALMENY BASALT:.

TUFF OR ASH; O.R Q.D. QUARTZ-DOLERITE;

TR. R TRACHYTE; A.M. _ _ ANDESITIC MUGEARITE

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numerous blocks of sandstone, embedded in a matrix of Markle basalt, stained red by iron-bearing solutions. Higher up, still more Jedburgh basalt occurs. This large development of tuff, cut by its numerous acid and basic intrusions, points to the occurrence of a definite vent; emphasis must also be laid on the frequent sandstone xenoliths found. Boulder clay makes it impossible to state definitely whether any lavas issued from here, but, in view of the macroporphyritic rocks appearing in the neighbourhood of Slackristock, it seems highly probable that they did. Drumbouy, which rises to the east, has Markle exposed on its southern face and Jedburgh on its northern. On both sides of this hill an overflow channel exists, as was previously mentioned. The northern tributary of the Faughlin Burn traverses a most varied section. As much of this as can be seen shows fine-grained basalt and mugearite, cut by numerous intrusions, associated with small dykes and patches of tuff. There is one sill of bostonite in which all the joint planes are horizontal, whereas in the dykes these are always vertical. In both dykes and sills vesicles are abundant. A dyke cutting the extrusives near here is a beautifully fresh Dunsapie basalt, which calls for special mention, as it was analysed and studied quantitatively under the microscope.

The only other piece of field work which need be described in detail is the behaviour of the large quartz-dolerite dyke crossing the north Kilsyth Hills. Evidence of the dyke was seen in the Burnhouse Burn just outside the western boundary, but from there to within a short distance of the March Burn no exposure was noted. In the March Burn it is seen, but it does not appear again for half a mile, when it is met in the Slackristock Burn. Then, for fully a quarter of a mile east of the latter stream the dyke forms a prominent scarp cutting the lavas before it once more becomes obscured further east. Thus it appears that although it may often be hidden beneath boulder clay, this alone will not account for its great variation in visibility, and it is possible that the dyke does not reach the surface of the lavas throughout a large part of its length.

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IV. Petrography.

Extrusive and Intrusive Types.

The classification of the Scottish Carboniferous lavas is a problem that has engaged the attention of several geologists, among whom are the following arduous workers:—Sir A. Geikie, Professor W. W. Watts, Drs. Teall, Hatch, and Flett, and Messrs. Bailey and Tyrrell.

That adopted here is the one formulated by Bailey,[6] with modifications suggested by Tyrrell.[7]

(1) *Macroporphyritic Lavas.*

(*a*) Markle Type.

Phenocrysts of plagioclase (labradorite-bytownite) in varying proportions are common. They are frequently zoned, and this may be best seen in sections parallel to the clinopinacoid (010). The outer zones are the most acid, being sometimes oligoclase, and there is often a zone of glass inclusions near their edges. The size of the phenocrysts varies continuously from 1 mm. upwards, large ones being as much as 20 mm. Many inviduals show Carlsbad and albite twinning, and that according to the pericline law is no rarity. In slightly weathered specimens hæmatisation has taken place, whilst the ease with which weathering proceeds seems to depend almost directly on the proportion of felspar phenocrysts present. Albitization[8] has acted occasionally, affecting the basic cores alone in some crystals, but the whole in others.

Microphenocrysts of olivine obtain in most of this type, and in a few cases the profusion is so great as to suggest the term Markle-Dalmeny as a fitting title for the rock. They have been decomposed into a green serpentine with a quantity of liberated magnetite in most cases, but iddingsite after olivine is not uncommon, and one specimen exhibited this mineral represented by quartz.

6 E. B. Bailey, *loc. cit.*, pp. 135-144.

7 G. W. Tyrrell, *loc. cit.*, pp. 225-232.

8 G. W. Graham and E. B. Bailey, "Albitization of Basic Plagioclase Felspars." *Geol. Mag.*, p. 251. 1909.

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The ground mass varies from a true ophitic plexus of labradorite and augite to a microlitic and granular mass with trachytically arranged felspar laths of intermediate composition. The lava from Berryhill (Pl. XXXIII., Fig. 1), Professor Watt's Kilsyth type,[9] as well as showing areas of ophitic texture, shows regions of a greenish material so common in the more decomposed granular varieties. The origin of this was not quite definite, and it was suggested that it was a result of decomposition of augite. In one slide, however, the green material and augite are occasionally in contact, the latter showing no signs of passing into the former through decay. Some of the indefinite substance was found included within a felspar phenocryst in small spheroidal masses, proving that it was taken up into the crystallising felspar in the liquid condition, and as this encloses both the augite and felspar crystals, it certainly solidified after them. The conclusion is that it is the product of the final fluid left in the rock which was withheld from crystallising until much undercooling had taken place, and as a result produced a very fine-grained matrix. The smallness of the grain would enable weathering to take place rapidly. Titaniferous magnetite is present in small quantities; apatite appears in the form of small needles and occasional grains; magnetite is abundant and mainly primary.

Sp. gr. = 2·76 – 2·83.

(*b*) Dunsapie Type.

Rocks of this type are uncommon, and it is doubtful if one which would agree with the type specimen[10] from Edinburgh is present, but there are at least two occurrences of a basalt which fit into the limited definition of the class. One of these with sparse augites and plentiful felspar macrophenocrysts occurs in the Garrel Hill. The other is a dyke rock (Pl. XXXIII., Fig. 2) in the northern tributary of Faughlin Burn, about 1000 yards from the reservoir.

The felspar is similar to that already described for the

9 A. Geikie. Watt's classification as quoted in "Ancient Volcanoes," p. 418. 1897.

10 J. S. Flett, "Geology of the Neighbourhood of Edinburgh." *Mem. Geol. Sur.*, pp. 316-318. 1910.

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Markle type. These phenocrysts are andesine-labradorite, and the groundmass laths are oligoclase-andesine. Augite of a yellowish, slightly pleochroic variety is present, and olivine, almost totally changed to serpentine, together with a few crystals of ilmenite, appears. The mode[11] was determined by Rosiwal's method, and the norm[11] calculated from the chemical analysis.

MODE.

	Groundmass, 82·5%.	Phenocrysts, 17·5%.
G.M.	Fels. = 62%.	Aug. = 26%
	Iron Ores = 11·5%	Apatite = 0·5%
Phenocrysts.	Fels. = 82·2%	Aug. = 8·8%.
	Olivine = 5·3%	Iron Ores = 3·7%
TOTAL,	Felspar, 65·5%	Augite, 23·0%
	Iron Ores, 10·1%	Olivine, 1·00%
	Apatite, 0·4%	

CHEMICAL ANALYSIS.

	I.	II.	III.	IV.
SiO_2	49·76	45·10	47·63	50·24
TiO_2	2·01	2·66	2·81	3·09
Al_2O_3	13·80	15·04	14·83	15·01
Fe_2O_3	6·72	8·85	3·13	8·94
eFO	7·68	4·62	8·48	6·46
MnO	p.n.d.	0·45	—	p.n.d.
MgO	2·86	6·68	6·77	3·16
CaO	7·46	8·75	13·04	5·61
Na_2O	4·70	3·78	2·26	3·47
K_2O	1·62	1·04	1·04	1·91
H_2O at 105	0·54	1·31	0·08	1·05
H_2O above 105	2·01	1·76		1·83
P_2O_5	0·39	0·56	0·28	p.n.d.
TOTAL,	99·55	100·60	100·35	100·77

(i) Dunsapie basalt (Andose). 1000 yards from Faughlin Reservoir in the Faughlin Burn, N. Anal. J. V. Harrison.

(ii) Dunsapie basalt (Camptonose). Duncomb Hill, Kilpatrick Hills. Anal. A. Scott. *See* G. W. Tyrrell, *Trans. Geol. Soc., Glasgow*, Pt. iii., vol. xiv., p. 201. 1912.

(iii) Dunsapie basalt (Auvergnose). Lava of 1905, Plain of Osmondes, Isle Reunion, Iddings Igneous Rocks, vol. ii., p. 590. 1913.

(iv) Mugearite (Andose). Mugearite from Creag a Mhara, S. Bute. Anal. J. V. Harrison. *See* W. R. Smellie, *Trans. Geol. Soc., Glasgow*, Pt. iii., vol. xv., p. 359. 1915.

[11] Cross, Iddings, Pirrson and Washington, "Classification of Igneous Rocks," p. 147. 1902.

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NORMS.

	I. (Andose)	II. (Camptonose)	III. (Auvergnose)	IV. (Andose)
Quartz,	—	—	—	8·16
Orthoclase,	9·45	6·12	6·1	11·12
Albite,	39·82	30·13	18·9	28·82
Anorthite,	11·68	20·85	27·2	20·02
Nepheline,	—	1·00	—	—
Diopside,	18·65	14·47	28·8	6·05
Hypersthene,	1·79	—	3·8	5·10
Olivine,	1·04	7·00	5·5	—
Magnetite,	9·74	8·58	4·4	11·60
Ilmenite,	3·80	5·17	5·3	5·93
Hæmatite,	—	2·88	—	0·96
Apatite,	0·67	1·34	0·7	—
Water,	2·54	3·07	—	2·82
	99·18	100·61	100·7	100·58

Sp. gr. of I = 2·81.

(*c*) Craiglockhart Type.

This occurrence has been duly noted[12] and described (Pl. XXXIII., Fig. 3). Suffice it to say that it is a rock in which numerous porphyritic crystals of olivine and augite are set. The groundmass is mainly ophitic with plentiful magnetite, thus departing slightly from the orthodox definition of the type.

(2) *Microporphyritic Types.*

(*a*) Jedburgh Type.

Most of the fine-grained rocks found within the stated boundaries are of this variety. Microporphyritic crystals of olivine and felspar, the latter forming a continuous series passing to macrophenocrysts in some specimens, and grading without break to the normal laths of the groundmass in others, are plentiful. This gradation unfortunately makes it impossible to fix a definite line of demarcation between the Markle and Jedburgh types. The groundmass may be ophitic, granular, or trachytic, and is invariably powdered by magnetite grains.

Sp. gr. = 2·77.

(*b*) Micro-Dunsapie Type.

The highest exposure in the westmost burn may be conveniently placed in this group, as it contains small, well-shaped bodies of olivine, augite, and felspar, set in a granular matrix.

12 A. V. Lothian, *loc. cit.*, p. 18.

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(*c*) Hillhouse Type is not found.

(*d*) Dalmeny Type.

One occurrence of this has been noted in the March Burn. The relations of the rock to the surroundings are obscure, it being only exposed in the bottom of the burn, and it is either a dyke cutting the tuff, or a boulder contained in it. The groundmass is very decomposed, while the numerous olivines are represented by pale green chlorite (Pl. XXXIII., Fig. 4).

(*e*) Mugearites.

There is a development of these which shows, instead of labradorite laths, oligoclase and oligoclase-andesine. They pass without a break to the former, however, forming therefore a series from true mugearite, through basaltic-mugearite, to Jedburgh basalt.[13]

Sp. gr. = 2·86.

The ash found is reddish purple, frequently bedded and traversed by irregular calcite veins. The quantity of agglomeratic matter is quite inconstant. The sandstone found in one of these masses has angular quartz grains cemented by calcite and hæmatite. The occurrence of sandstone xenoliths in a dyke S.W. of Waterhead was noted by Mr. Bailey.[14]

Bostonite and Keratophyre.

Rosenbusch defines the former as a white, yellow, grey, or grey-green, fine-grained rock, which is sometimes trachytic, sometimes compact, and has a soft satin-like appearance. It is composed mainly of alkali felspar.[15] Iddings regards it as a partially weathered trachyte,[16] and Harker[18] and Hatch[17] point out that it should contain very little ferromagnesian mineral.

It is typically a dyke rock, whilst trachyte is a lava. Several

13 G. W. Tyrrell, *loc. cit.*, p. 249-252.
14 E. B. Bailey, *loc. cit.*, p. 110.
15 H. Rosenbusch, "Elemente der Gesteinslehre," p. 269. 1910.
16 J. P. Iddings, "Igneous Rocks," vol. i., p. 366. 1909.
18 A. Harker, Petrology for Students, p. 129-131. 1908.
17 F. H. Hatch, "Petrology of the Igneous Rocks," p. 238-239. 1914.

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intrusions were found to have microscopical characters which placed them in this group. A few are markedly porphyritic, but others are fine grained and without macrophenocrysts. The texture of the majority is trachytic, the felspar laths being arranged in fluxion bands (Pl. XXXIII., Fig. 5). Many are slightly vesicular. The phenocrystic felspars are probably anorthoclase and occasionally oligoclase. The laths composing the mass of some slides are either not twinned, or twinned simply, and are therefore orthoclase, or soda orthoclase, *e.g.*, dyke in the Slackristock Burn, about 300 yards from the farm. But in the majority much of the felspar is indeterminable through decomposition. Occasionally laths occurring in fresher patches give extinction angles up to 8°, and may thus be albite. Very probably, however, most of these are slightly calcic, and are albite-oligoclase. Quartz is plentiful, being both primary and secondary, and with it a greenish chloritic material is often associated, the two filling up many of the interstices between the felspar laths. Magnetite is present in small quantities. A determination of the alkali content of one of these has been made—$K_2O = 2{\cdot}71\%$ $Na_2O = 5{\cdot}85\%$. Rock analysed was that contiguous to the large E.W. quartz dolerite dyke in the March Burn (Pl. XXXIII., Fig. 5).

One or two other dykes have a similar constitution, but have an entirely cryptocrystalline matrix, in which weathered anorthoclase crystals can be distinguished. These are therefore keratophyre.

Sp. gr = 2·59 – 2·66.

A dyke in the March Burn is composed of numerous oligoclase laths in a decomposed microlitic base. The rock may be termed an andesitic mugearite.

Sp. gr. = 2·68.

The large E.W. quartz dolerite dyke shows the usual variations in mode from point to point.[19] In some places it contains fresh augite, whilst elsewhere this constituent is wholly decomposed. Ilmenite and pyrites occur, and everywhere micropegmatite is abundant. A measurement across several slides by

19 G. W. Tyrrell, "Geology and Petrology of the Kilsyth and Croy Intrusions." *Geol. Mag.*, V., vol. vi., pp. 306-9. 1909.

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the Rosiwal method gave the following proportions among the constituents present:—

Felspar and Micropegmatite = 77·1%	Augite = 14·8%
Magnetite = 4·6%	Serpentine = 1·1%
Pyrites = 1·0%	Quarts in blebs = 0·9%
Apatite = 0·5%	

V. Petrology.

The plateau eruptions giving rise to the Kilsyth Hills, and to the more extensive hills to the north and west, occurred after a prolonged period of sedimentation. The rocks here overlain comprise the lower part of the Calciferous Sandstone Series of Carboniferous Age, the Upper and Lower Old Red Sandstone, and probably rocks of Silurian to Dalradian Age. The basalts forming the plateau were thus extruded over a synclinorium, the ideal conditions suggested by Daly for such occurrences.[20] As Mr. Bailey has pointed out, the main centres of extrusion[21] were placed one in the west, giving rise mainly to Jedburgh basalt, and one near Kilsyth, giving mainly Markle. It seems probable, however, in view of the field evidence collected from the East Kilsyth Hills, that other quite definite vents existed, and gave rise locally to other types. That one vent extruded only one type seems highly improbable, considering the great variations which contiguous flows exhibit in regard to the proportion of phenocrysts to groundmass present. These differences are of physical origin depending on the rate at which the lava flowed through the throat of the volcano, and the conditions of cooling.

This is emphasised by the close chemical and mineralogical affinities of the Jedburgh and Markle types of basalt, which point to their originating in similar, if not in identical, magmas. Which type issued was determined in the throat, for it must have been here that the porphyritic crystals were at least partially formed.[22] If the cooling magma be moving slowly up a volcanic pipe, it may arrive at such a point that it becomes saturated with respect to a certain mineral constituent owing to decreasing temperature. From such a solution

20 R. A. Daly, "Igneous Rocks and Their Origin," p. 185. 1914.
21 E. B. Bailey, *loc. cit.*, p. 100.
22 R. A. Daly, *loc. cit.*, p. 376.

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crystals will commence to separate, and being subjected to a very gentle cooling will be able to keep in equilibrium with their mother liquor. Moreover, this crystallisation has a chance to take place while the liquid is still in the metastable state,[23] and so the large crystals grow at only a few centres of crystallisation, since these do not tend to multiply until the labile state is reached.[24] This, then, explains the unzoned nature of the centres of the phenocrysts found in the lava.

Further, the gradual crystallisation would work a steady change on the composition of the magma, till a binary eutectic point is reached. Two minerals would then crystallise together, but as cooling is very gentle, perfect crystals of two minerals could form without interfering with one another, so long as ample fluid was present.

Olivine and felspar tend to form here in normal circumstances,[25] and the progressive removal of these two constituents would cause the system to approach the conditions necessary for augite to be a stable phase. To explain the occurrence of numerous felspar, and a few but still large augite phenocrysts in the one rock, such conditions would be suitable, the large size of the augites being explicable on account of their having a greater crystallisation velocity than felspar. The latter has to make equal additions to all the existing crystals, whilst the augite grows at still scanty centres.

At the instant of extrusion the conditions would be entirely altered, and the above cooling history would no longer apply. The rapid cooling and relief of pressure ensuing would cause many minerals to become saturated in the molten lava, and hence an entire change in the conditions of equilibrium between the phases present would be produced. It was probably at this stage, as Fenner points out,[26] that the many small pseudomorphs after olivine so commonly seen in the Kilsyth lavas took

23 C. Doelter, "Physikalisch-chemische Mineralogie," pp. 111, 112. 1905.

24 H. A. Miers, Pres. Address, Sect. C. *Report of Brit. Assoc.*, p. 389. 1905.

25 MM. L. Bowen and Olaf Andersen, "The Binary System $MgO.SiO_2$." *Amer. Jour. Sci.*, pp. 499-500. 1914.

26 C. N. Fenner, "The Crystalisation of a Basaltic Magma from the Standpoint of Physical Chemistry." *Amer. Jour. Sci.*, series 4, xxix., p. 228. 1910.

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up the form they now have, through the partial or complete resorbtion of the olivine crystals formed in the intratelluric crystallisation. This alone can explain the persistent occurrence of "weathered" olivines throughout the series of otherwise fresh rocks. Experimental work done in the Geophysical Laboratory has proved that resorbtion of fosterite takes place in a pyroxene bearing melt during cooling.[27]

During this period also the zones round the felspar nuclei already present are developed. A large crystal grows at the expense of little ones of the same substance,[28] so that when a material has the option of forming laths or adding to an already considerable growth it chooses the latter. Hence it is surmised that quite an extensive rim will affix itself round existing phenocrysts. The crystals will now be cooling too rapidly for one layer of felspar to keep in equilibrium with the ever-changing felspar solution, which will therefore deposit varying zones. The outside zones are more acid than the internal ones, and sometimes more acid than the laths of the groundmass, though the basic centres are always more basic than these. Albite-anorthite forms a series of miscible melts, which conform to Roozeboom's type 1,[29] of two completely miscible solutions, and therefore as cooling proceeds there must be a steady increment in the liquid phase of the constituent with the lower melting point, if cooling proceeds too rapidly for equilibrium to be constantly maintained. In this case the melting points of the two components are approximately known.[30]

	M.P.
Anorthite,	1532.
Ab_3An_1,	1340 (liquidus).
Albite,	1250 (uncertain).

The result therefore will be exterior layers rich in albite.

The final transfer of material may not happen until viscosity has become so great that only ionic movements can take place.

27 O. Andersen, "The System Anorthite, Fosterite, Silica." *Amer. Jour. Sci.*, series 4, xxx., p. 449. 1915.

28 J. V. Elsden, "Principles of Chemical Geology," p. 62. 1910.

29 H. W. B. Roozeboom, "Zeit. f. Phys. Chem.," xxx., pp. 387-394. 1899.

30 Day and Allen. *Amer. Jour. Sci.*, xix., p. 140. 1905.

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A point of interest is attached to the modes of occurrence of the augite in these basalts. It is sometimes associated with felspar in ophitic relations. This texture is generally held to be due to the augite remaining liquid until the felspar had finished crystallising, but it has been described recently as a eutectic intergrowth.[31] If this assumption were correct, many instances of the restricted growth of individuals of both mineral species should be observable. In the diagram Figs. (*a-d*) represent the possible successive stages

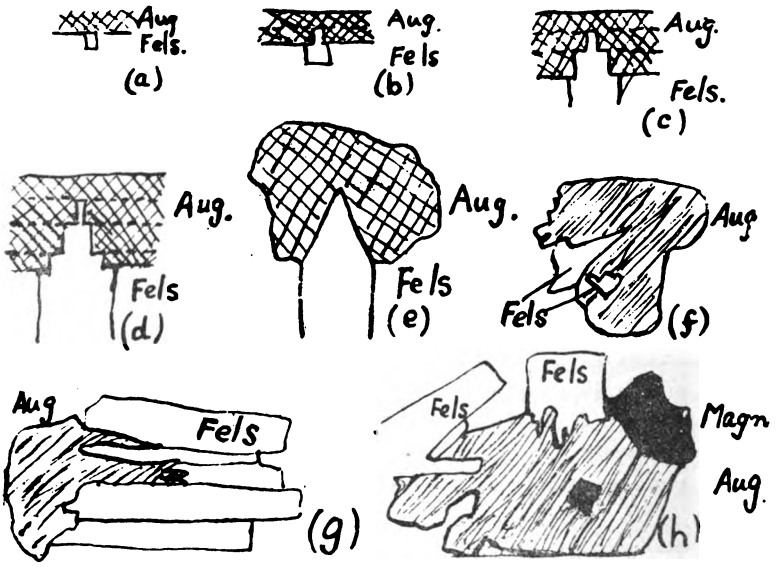

Diagram to illustrate the growth of an Augite.

in the growth of an augite and felspar crystal if they were originally contiguous, and Fig. (*e*) the texture which would result. Figs (*f*), (*g*), and (*h*) are drawings of intergrowths seen in the Berryhill lava, which lend considerable support to the hypothesis of simultaneous growth.

The texture does not seem to have been entirely determined by the percentages of the two minerals present. In a few of the lavas augite appears as small idiomorphic bodies embedded in

31 C. N. Fenner, *loc. cit.*, pp. 225-227.

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the felspar (Pl. XXXIII., Fig. 6). For this variation in texture there is no very apparent reason. The felspar crystallisation was delayed, and the large number of augites point to very many centres, such as could only be formed in a solution in the labile condition.[32] The amount of augite present is not such as to indicate that it ought to have saturated the magma first, and, even if it had done so, there would be no accounting for the early cessation of crystallisation, except on the grounds of almost complete insolubility in the residual liquid, or a change in the conditions so that augite was no longer deposited as a stable phase from the cooling melt. This can only be explained on the assumption that some common flux, usually present, was absent, or that the augite itself was of abnormal composition. The possibility of immiscibility of liquid augite in the melt may be dismissed.

VI. Conclusions.

(*a*) Within the limits of the east Kilsyth Hills there has been considerable glacial action, giving rise to terraced boulder clay, dry overflow channels, old intra-morainic lakes, and terminal and lateral moraines.

(*b*) The lavas appearing are of four main types—Markle, Jedburgh, and Craiglockhart basalts, and mugearite. The first, second, and fourth of these occur mixed with one another in all possible ways. The first forms the eastern and southern parts, whilst the second is most strongly developed in the northern. Craiglockhart underlies all others in the south-west, and the mugearite occupies a limited area in the north-east.

(*c*) Dykes and plugs of porphyritic and non-porphyritic bostonite, keratophyre, andesitic mugearite, Markle, Jedburgh, Dalmeny, and Dunsapie types of basalt, and quartz-dolerite occur.

(*d*) Besides small irregular patches of tuff, separating lava flows, one fairly large area occurs near the March Burn. This is believed to be the site of an old volcanic vent.

(*e*) The origin of the porphyritic types of lava is attributed to their magma having been subjected to a longer cooling in the

[32] H. A. Meirs, *loc. cit.*, p. 389.

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volcanic throat than the magma of the fine-grained varieties experienced.

(*f*) The zoning of the plagioclase phenocrysts is due to the rapid cooling of a solution of two materials which form mix-crystals with each other. When cooling is too rapid for the liquor to remain in equilibrium with the solid forming from it, the anorthite, having the higher melting point, is enriched in the crystals and the albite concentrated in the solution, thus accounting for the acid exteriors of the zoned felspar crystals.

(*g*) The occurrence of ophitic texture in some rocks and not in others in which the augite, instead of being intergrown with felspar, is enclosed by it, is apparently due, not to great differences in chemical composition of the whole rock, but rather to the presence or absence of indefinite bodies during the solidification of the magma.

In conclusion, it only remains to thank numerous friends for their interest and help. Especially to Professor Gregory for suggesting the work, and for helpful advice throughout I am particularly indebted, to Mr. G. W. Tyrrell for assistance with difficulties in the microscope work, and to Mr. W. R. Smellie for sympathetic criticism in the field. The cost of the illustrations accompanying this paper has been kindly met by the Carnegie Trust.

PLATE.

FIG. 1 x 20.—Markle basalt, Kilsyth variety, showing macrophenocrysts of felspar, some magnetite, pseudomorphs after olivine, and a groundmass with ophitic texture. 300 yds. N. of Berryhill Farm

FIG. 2 x 20.—Dunsapie basalt, showing a large augite in the centre of the field, and some felspar crystals embedded in a groundmass of felspar, granular augite and magnetite.

Dyke, 1000 yds. N. from Reservoir, Faughlin Burn.

FIG. 3 x 10.—Craiglockhart basalt, with numerous porphyritic crystals of augite, and large pseudomorphs after olivine. Lowest lava flow in Garrel Burn.

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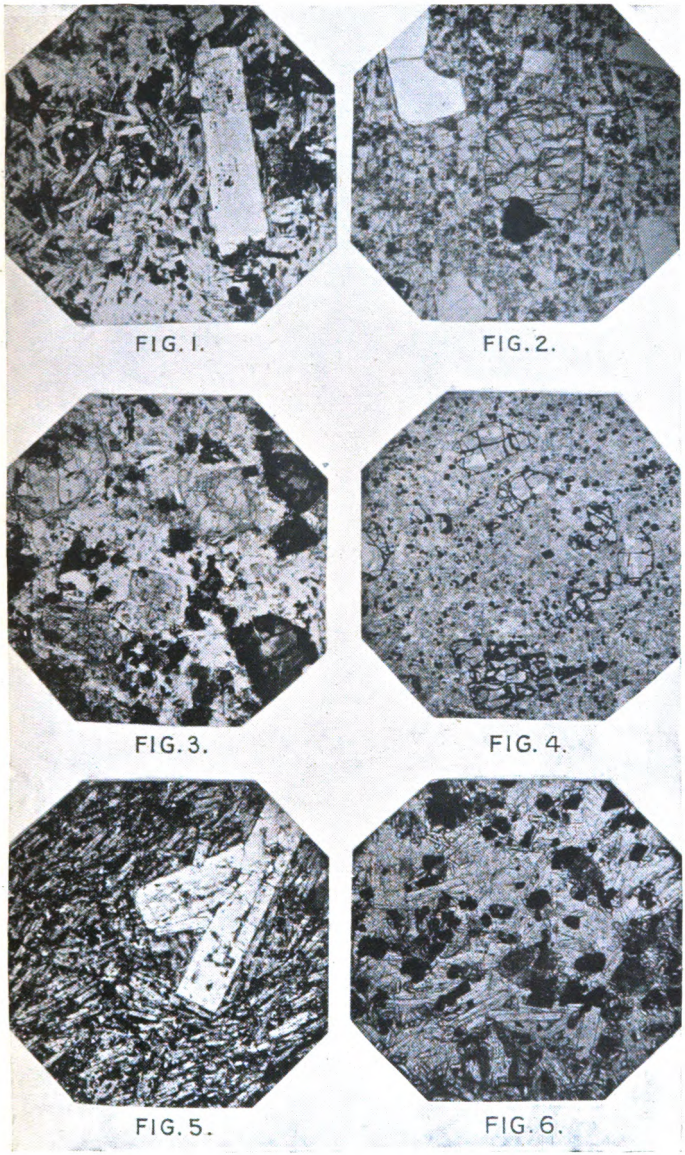

Photomicrographs of Rocks from the East Kilsyth Hills.

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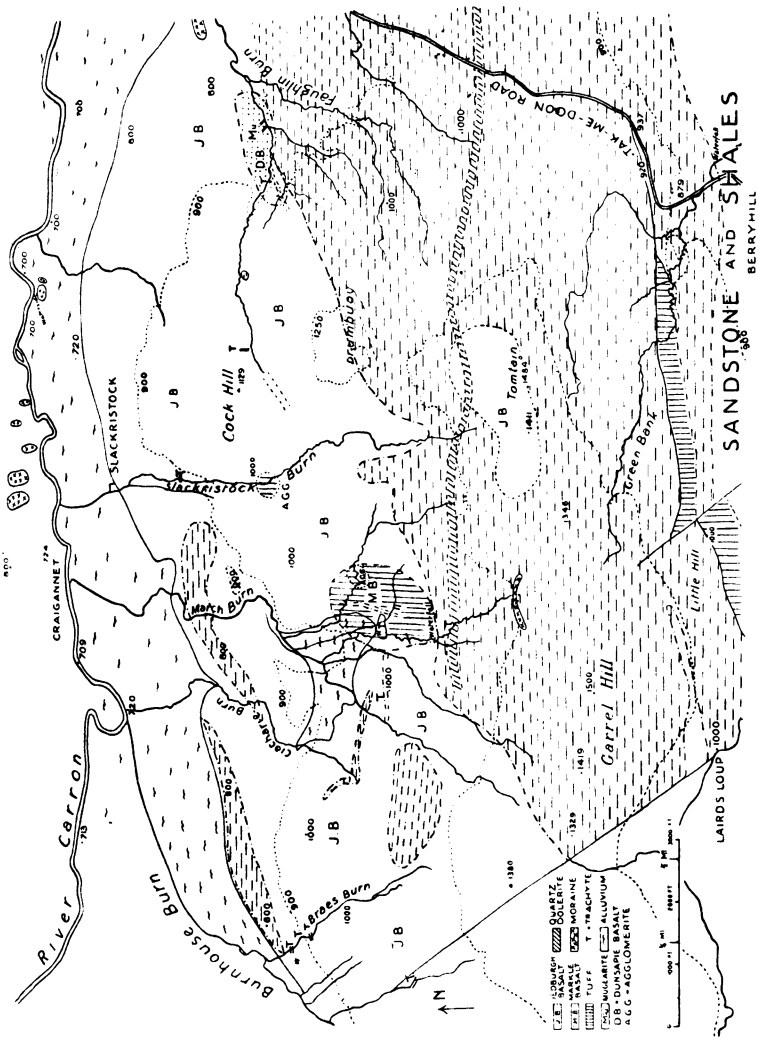

Map of the East Kilsyth Hills.

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FIG. 4 x 20.—Dalmeny basalt, showing pseudomorphs after olivine and decomposed groundmass.

Dyke, 70 yds. N., of quartz-dolerite dyke, March Burn.

FIG. 5 x 20.—Bostonite, exhibiting phenocrysts, and trachytically arranged laths of felspar.

Dyke contiguous with the quartz-dolerite dyke, March Burn.

FIG. 6 x 90.—Markle-Jedburgh basalt, in which the augite occurs in habit of small idiomorphic crystals.

Money Knowe, Little Hill.

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No. XXI.—The Igneous Rocks of Bute.

By William R. Smellie, M.A., B.Sc., Hunterian Museum, Glasgow University.

[Read 11th February, 1915; issued separately 10th February, 1916.]

The geological claims of Bute seem always to have been overshadowed by the near presence of Arran, with its superior size and variety of formations. MacCulloch, in his "Geology of the Western Islands" (1819, p. 445), devotes some space to emphasising the importance of Bute geologically, and then dismisses the island in twenty-nine pages. Bryce, in his "Geology of Arran and the other Clyde Islands" (1872), reproaches MacCulloch for his injustice, and then generously allows Bute three pages more, or thirty-two pages, as against 315 pages devoted to Arran. The object of the work recorded in the present paper has been to continue and amplify the work recorded in the Geological Survey Memoir (1903) as far as it relates to the igneous rocks of Bute. The igneous rocks in the area have been mapped and studied with the aid of numerous thin sections under the microscope. The lavas of Calciferous Sandstone age will be described in the light of recent classification, certain occurrences of rocks hitherto unknown in the district will be recorded, while in some cases evidence will be advanced which may necessitate change in the interpretation of rocks already described.

Distribution of the Igneous Rocks.

The Island of Bute is divided into approximately equal halves by the Highland Boundary Fault which crosses the island from Rothesay Bay to Scalpsie Bay. The northern half is composed of Highland schists, grits, and phyllites, and the igneous rocks are confined to a few dykes and the Scalpsie epidiorite sill. The dykes running east and west are thick and persistent, and are granophyric quartz-dolerites of Permo-Carboniferous age, while those with a north and south trend are Kainozoic dolerites. The southern half of the island is occu-

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pied for the most part by rocks of Upper Old Red Sandstone age, chiefly conglomerate and sandstone with some cornstone. Many dykes intersect those rocks, Kainozoic dykes being specially numerous. The sediments dip south-west, but are so repeated by faults that, with the exception of small outliers of lava at Ascog, Ambrisbeg, and Ardscalpsie, Old Red Sandstone occupies all the country between the Boundary Fault and the raised beach which crosses the island at Kingarth. South of this (see map) igneous rocks occupy the bulk of the ground, giving long, regular escarpments of bare lava, sill escarpments, and isolated vents, and producing a barren, rugged country, only relieved by the flats of the raised beaches. Except for the Suidhe vent, above Kilchattan, the country seldom rises above the 400 feet contour, but under hazy atmospheric conditions the small abrupt hills and ridges can look quite massive, and this may account for a singular over-estimation of heights given by MacCulloch (1819, p. 446). He gives the height of the Garroch Head district as 600 to 800 feet, while for the raised beach, crossing the island at Kingarth, which no more than breaks the 50-feet contour, he estimates a height of 300 feet.

Among the igneous rocks of Bute are found representatives of four periods of igneous activity—

	Rocks.	Age.
I.	Epidiorite Intrusion of Scalpsie.	Arenig?
II.	Basaltic and Trachytic Lavas, Ash, and Agglomerate: Minor Intrusives, one of which contains fragments of Plutonic Rocks.	Calciferous Sandstone.
III.	East and west dykes of Quartz-Dolerite. Large sill of Olivine-Dolerite, and doubtfully several small dykes and sills of the same rock.	Permo-Carboniferous.
IV.	Composite sill of five sheets, and numerous dykes and inclined sheets of Dolerite.	Kainozoic.

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Epidiorite and Serpentine of Scalpsie Bay.

Although previously described separately (Gunn, 1903, p. 22) these two rocks are here taken together as both field evidence and thin section indicate that they form parts of one and the same intrusion. It occurs on the west side of Scalpsie Bay, and forms a low but well-marked ridge, which runs from a short distance north of the Dun to the cliff of the raised beach, fully a quarter of a mile to the south. Here the outcrop is interrupted by raised beach material, but continuations of the lines across to the present beach pick up the rock again there. It is exposed about high-water mark, and is got rather irregularly owing to the mantle of large boulders which strew the beach and mar the exposure. It is from this part that serpentine has been described, and while serpentine certainly occurs, it by no means constitutes the whole of the mass on the beach, for another specimen from hard by may be devoid of serpentine. This exposure is undoubtedly only the more altered southern end of the epidiorite, which rock has been intruded as a sill at least 100 feet thick at the Dun, which forms its highest point. It dips west into the grits and quartzites which form its northern and western boundaries, but no sharp junction is got, as the ridge of epidiorite is separated from the overlying grits by a small turf-clad depression or a boulder-strewn hollow. On the east side it is bounded by raised beach material, while to the south, intervening between the sill and the sea, occur bars of red and white sandstones with interbedded clays. These are probably of Lower Carboniferous age, and are much disturbed, great variations in dip both in amount and direction being got within a few yards. The boundary fault runs between the sandstones and the southern end of the sill, but the actual fault line, occurring as it does well below high-water mark, is obscured in a tantalising fashion.

Petrography.—In the hand specimen the epidiorite is a dark-coloured thoroughly foliated rock, varying greatly in texture from a fine-grained amphibolite, with black shining hornblende needles to a coarse variety showing large plates of hornblende and a less well-marked parallelism of constituent minerals. The various grades can be got in one small block of the rock,

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and do not appear to occur in any particular relation to positions in the sill. Veins of felspar, ranging up to 1 or 2 inches in thickness, are frequently met with traversing the mass, and when the vein has not been completely filled, felspars showing crystal faces are got projecting into the vugg. Veins of quartz and calcite also occur, and at a point about 100 yards south of the Dun a pocket of calcite about a foot in diameter was observed.

Thin sections were cut from specimens of the epidiorite taken from the northern extremity, the Dun, and several positions to the south. Slices from the centre of the mass show the least altered rock. It is a coarse aggregate of pale green hornblende, felspar, and quartz. The hornblende is drawn out and ragged, and is frequently replaced by chlorite. The felspar is partly cloudy, probably due to minute grains of epidote, separating out, and partly clear secondary albite. The albite and quartz are clear and granular, and sometimes occur mainly in the veinlets. Epidote and zoisite, though always present, vary greatly in amount, and the epidote frequently becomes one of the chief constituents of the rock. It occurs as strings and aggregates of elongated pale green grains with appreciable pleochroism and high single and double refraction. The zoisite grains are less numerous, and in some slides, absent. It occurs as colourless grains, with very typical steel-blue interference colours. In the "serpentine" exposure on the shore more highly altered rock is got. One section shows little original hornblende, epidote, the main constituent, with a few wisps of chlorite drawn out in the centre of epidote aggregates, while quartz and felspar are very irregular in amount (Pl. XXXVI., Fig. 6). Some fields show almost pure epidote rock, while others show the rock passing locally into epidosite, an epidote quartz rock. There is great variety in this shore exposure, and it is unfortunate that only occasional projections of the rock *in situ* appearing through beach material are available. Another specimen from this locality is very pale green in colour, and in thin section proves to be completely composed of high polarising fibrous talc, while a third, dark and foliated, and not unlike the amphibolite in appearance, proves to be almost entirely colourless serpentine.

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without a trace of the parent mineral or hint of its nature. The serpentine is in sheaves and bundles of fibres giving extinction brushes; a little stringy magnetite is present, and a few grains of epidote and zoisite survive. In the talc no trace even of the epidote remains. Between cross nicols the section of the talc shows a few areas of low colour, presumably serpentine interleaved with the highly polarising talc fibres, but in the serpentine rock no talc is observed in the thin section, although the rock scratches easily with the finger nail, and gives a sp. gr. of 2·8.

The large felspar veins are of perfectly clear albite, but in the small veinlets of albite seen in the slices of the epidiorite numerous small prisms of secondary hornblende occur. Where these veins cross hornblende crystals the secondary outgrowths of hornblende are often in optical continuity with the large broken crystal. The albite has been derived from the soda-bearing silicate in the original lime-soda felspar, when the lime-bearing silicate separated out to form the zoisite and epidote. The formation of epidote, zoisite, and chlorite in epidiorites is common, but the formation of serpentine from an amphibole rock is rather unusual, though occasionally recorded. (Emerson, 1898, p. 115.)

The age of the intrusion is uncertain. The thin section under the microscope gives no clue, as it is found to differ in no essential from other Highland epidiorites, such as those in the Strachur district. From field relations it seems that it was intruded probably as a dolerite in pre-Boundary Fault times, and metamorphosed to epidiorite by the same movements that metamorphosed the grits into which it is intruded. The further dynamic metamorphism suffered by its southern extremity is to be ascribed to the movements forming the Boundary Fault, which movements appear to have continued into Carboniferous times. Arenig has been tentatively put forward as the age of the intrusion (Gunn, 1903, p. 22), and this does not seem improbable.

Carboniferous Igneous Activity.

The rocks of Lower Carboniferous age form the bulk of the igneous material in Bute, and consist of basaltic and trachytic

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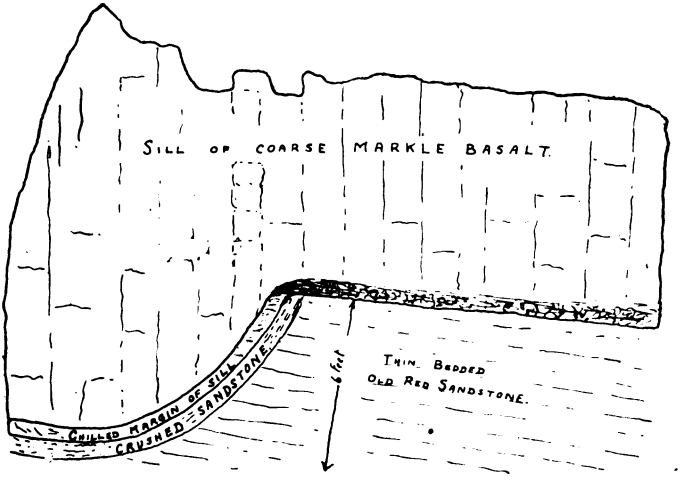
lavas, necks of agglomerate, beds of tuff and minor intrusives, while evidence of the existence of a plutonic phase is found in a suite of basic and ultrabasic rocks occurring as xenoliths in one of the minor intrusions.

Field Relations.—The lavas overly the sediments of Old Red Sandstone and Calciferous Sandstone age, and dip to the south-west at angles of about 20° to 30°. In direction and amount the dip is approximately the same as that of the



Diagrammatic section of north face of Barn Point, showing sill of Markle Basalt cutting across the bedding planes of Sandstone.

underlying sedimentary rocks, so that in any one section across the junction an unconformity is not apparent. [As will be seen later, the evidence of the section at the south end of Lubas Bay is inadmissible for purposes of demonstrating an unconformity (Gunn, 1903, p. 55), as the rock in question is a sill and not a lava. (See text figure.)] However, the unconformity can be proved by the different horizons in the sedimentaries at which the lavas are found to commence in different parts of the field, showing that the lavas have transgressed over the thin Calciferous Sandstone Series into the Old Red Sandstone. The unconformable nature of the junction can be further shown by a comparison of the sediments immediately beneath the lavas at two points only 300 or 400 yards

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apart. At Creag a Mhara the sediments end with about 40 feet of reddish sandstone, in places baked and columnar by invasion, while just across the Hawk's Nib fault, towards Run-nan-Eun, the topmost sedimentaries consist of 20 to 30 feet of greenish-white sandstone, followed by 2 feet of clay, then 2 feet of white sandstone, and, finally, in contact with the lava, 3 feet of clay.

The lavas strike north-west in long ridges, which are frequently columnar, and strike faults throwing down to the north-east break the peninsula south of Kilchattan into several blocks separated by long, straight valleys. These features were observed and neatly described by Boué (1820, p. 257) in his "Essai Geologique sur l'Ecosse." Three of the faults have sufficient displacement to bring up the sediments at the base of the lavas on the upthrow side, thus multiplying opportunities for comparing the sequence of the early lavas in different parts of the field. The various blocks of lava, marked off by the faults, will be described separately and referred to under the names of prominent topographical features occurring in them or bounding them; the points of emergence of faults on the shore will be found useful centres in referring to the map. Following the shore from Kilchattan south, the first lavas met with are those of Creag a Mhara. Creag a Mhara is a large vent piercing the Calciferous Sandstones, which are seen on the shore around its base. It forms the tall cliff of the raised beach, on the bare side of which the large boulders of the coarse agglomerate can be seen from a distance, while from its summit the lavas which it emitted stretch inland, in a north-westerly direction, nearly to the Kilchattan waterworks. These Creag a Mhara lavas form only a narrow strip, for at Hawk's Nib, a short distance further on, the first strike fault emerges on the shore, Hawk's Nib being a prominent undercut cliff of red sandstone on the upthrow side of the fault.

Continuing south over sandstones and cornstones, which are much invaded by igneous rock, the lavas are soon encountered a second time, and are associated with a neck of agglomerate very similar to Creag a Mhara. This Run-nan-Eun block of lavas is much larger than the last, and extends to the Suidhe

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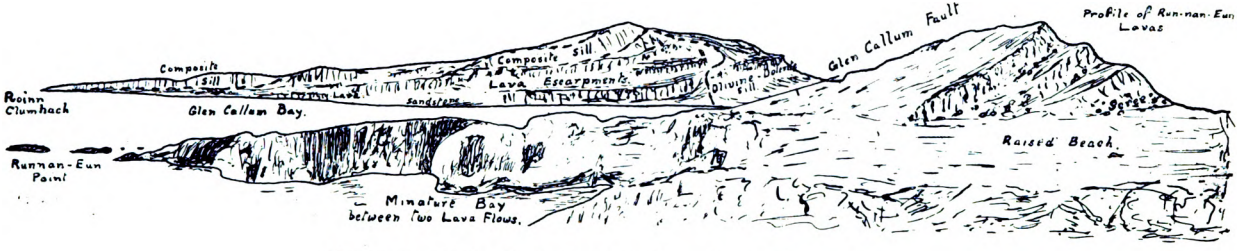
Photo. by J. W. Reoch, Esq.



Panorama of South Bute, taken from Run-nan-eun Point.

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Hill, the large vent above Kilchattan, with its associated lavas. On Run-nan-Eun there are about a dozen flows, averaging about 30 feet thick, and the flows are frequently separated by beds of ash, which are sandy and occasionally attain a thickness of 4 feet. Where the lavas abut on the sea the differential action along the strike of the flows on the soft ash beds or scoriaceous junctions has resulted in numerous miniature bays and promontories, producing a very rugged coastline (see Pl. XXXV.). Inland the flows rise in terraces one above another till the long dip-slope of the topmost flow descends into Glen Callum, where the strike fault forming that valley abruptly terminates the series.

Across the valley lavas are seen again, rising terrace upon terrace to a height of 400 feet, but these are the beginning of the series again, for, on the shore of Glen Callum Bay the first lava is got resting on sandstone (Pl. XXXV.). Seen from the top of Run-nan-Eun the lava terraces stretching along the north-west side of Glen Callum are very imposing, and it may have been their regular superposition that caused MacCulloch (1819, p. 465) to state that "among the numerous instances of apparent stratification in trap which have occurred in the course of this survey, the present (Bute) is infinitely the most regular and perfect." This Glen Callum block of lavas consists of about twenty flows, and stretches to the strike fault which emerges on the shore at Port Uisg, and again brings up the sediments on its upthrow side. This is the largest of the lava blocks, but some of its extra extent may be accounted for by a partial repetition due to a possible fault running out at Port Leithne. The shore topography of this area is similar to that of Run-nan-Eun, but here the similarity ends, for the main feature inland is the dominating escarpment of the composite sill truncating the low-lying lavas and then sweeping round parallel to them. The olivine-dolerite sill cutting across the Run-nan-Eun lavas leaves no outstanding feature. Further variety is added to the Glen Callum block by the low elevation of the ground around Loch-na-Leighe, which must have been an arm of the sea at the time of the raised beach, with the composite sill escarpment acting as a protecting reef.

South-west of the Port Uisg fault, and overlying the sand-

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stones, stretch the Port Uisg—Dunagoil lavas, bounded to the north-west by the Dunagoil dip fault. Before these lavas have opportunity to accumulate into a block like the last they are bounded by the sea coast, which runs parallel to the strike of the flows. This gives a less serrated coastline, although at one point, at the boathouse of South Garrochty, the sea has breached one lava flow and then cut along the strike at the junction with the next, thus forming a small natural harbour with breakwater. There are about half a dozen different flows of lava in this block, and agglomerate and tuff are well developed. The north face of Dunagoil Fort shows the rocks well. The lavas are seen resting on the sandstone and dipping south-west. One of the flows is beautifully columnar, and the topmost flow, which reaches the sea, is pillowy, the pillows being best seen along the shore. A fairly thick ash bed outcrops beneath the lava, giving an undercut cliff on the north, and the fretting of the same ash bed where it meets the raised beach has produced one of the caves in which the prehistoric kitchen-midden material has been found. There are only about half a dozen lavas in this block, chiefly of markle type, but the development of agglomerate and tuff exceeds that in any other part of the area.

Ascog, Ambrisbeg, and Ardscalpsie.

These small outliers of lava, though insignificant compared to the lavas of the south end of Bute, have been the subject of more frequent reference, owing to the seams of coal got in association with those of Ascog and Ambrisbeg. The Ascog lavas form a small plateau stretching from Loch Ascog to the sea. They overly Calciferous Sandstone sediments exposed on their northern margins, and are faulted to the south against the Old Red Sandstone. The lavas composing the mass are chiefly mugearites, markle, and jedburgh basalts, with beds of tuff near the base. The flows seem to have been small and impersistent, and long, regular terraces are absent. The coal seam occurs near the base of the series intercalated between a very coarse and much-weathered markle basalt above and a bed of very crumbling rock, probably tuff, below. The section has been described in detail by Bryce

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(1872, p. 318). The lavas of Ambrisbeg lie between the south end of Loch Fad and the north-east side of Loch Quien; they are bounded to the north-west by the Boundary Fault, while to the south-east their escarpments shade into the raised beach. They overly red sandstone, which is seen on the east side of Loch Quien dipping west at a high angle. The lavas here are also notable for the absence of persistent terraces, the flows being apparently of small extent. Mugearites, markle, and jedburgh basalts are present, but the most noteworthy point about the lava types is the number of markle-dunsapie basalts that occur, and this area certainly contains a higher proportion of dunsapie and transition types than any other part of the field. Coal is reported to have occurred among the lavas here, as at Ascog, and the remains of an old adit can be seen near Ambrisbeg Farm, but no other evidence of the coal remains. The Memoir (Gunn, 1903, p. 146) reports that "some 200 or 300 tons of coal were said to have been got out many years ago," the coal being a "kind of anthracite," in a seam "from 1 foot to 16 or 20 inches thick." On the other hand, MacCulloch (1819, p. 472) reports the coal in the sandstone, but indicates that there was no access to the spot, as it had been filled up after an unsuccessful pursuit. Judging from the unsuccessful attempts to work the much thicker seam at Ascog, and considering the poor quality of the coal, it seems highly probable that MacCulloch is right.

At Ardscalpsie Point occurs a patch of Carboniferous Basalts that are probably lavas. They can only be reached at low tide, are very badly weathered, and their relations can be only indifferently made out. They are separated from the Boundary Fault by the strip of calciferous sandstone and conglomerate which runs along the north-west shore of Scalpsie Bay, and they are intersected by a north and south Kainozoic dyke of ophitic dolerite, olivine free. Thin sections of two specimens prove to be markle basalt and mugearite, but they are so decomposed that little can be made out of them.

Sequence of the Lavas.

In the lavas of the Campsie Fells a definite sequence is found to hold throughout the area (Bailey, 1911, p. 99). In

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South Bute the area is small, exposures are both good and plentiful, and the arrangement of the lavas, owing to frequent repetition by faults, is open to study at many points; under such favourable circumstances it was hoped at first that a very definite sequence might be made out and found to hold throughout the area. However, comparing several series of lavas, working from the base lava upwards, and employing localities separated by distances measured only in hundreds of yards, it was found that no uniformity in the order of the flows existed, nor was it possible to determine any general sequence among mugearites, markle, and jedburgh basalts. Any attempt to formulate a general rule of succession among these was immediately frustrated by the host of exceptions, and the conclusion reached was similar to that arrived at by Tyrrell (1912, p. 255) for the Kilpatrick Hills, namely, that "no divisions of general application can be profitably made." Lavas of mugearite, markle, and jedburgh type occur throughout the area, and a definite horizon cannot be ascribed to any one type more than another. However, it is noticeable in the lavas between Glen Callum and Port Uisg that it is near the top of the series that the extreme acid and basic types are got. No other lava block contains so many flows as this, and so none can be used to prove or disprove this in other parts of the field; but, judging from this one case where lavas of higher horizon are present, these seem to show an increasing divergence from the initial type. Throughout south Bute mugearite, markle, and jedburgh types occur at all horizons, but more acid types, bostonites, and more basic types, dunsapie and craiglockhart basalts occur chiefly near the top of the sequence. Thus it might be said, in a broad and general way, that the sequence is one beginning with intermediate lavas, mugearites, markle, and jedburgh basalts and passing into types, on the one hand more basic and on the other more acid than the original types. The development of the divergent types is very meagre, and at the top of the succession they do not occur to the exclusion of the intermediate types, and, in fact, do not even preponderate over them. This lack of a definite general sequence and the lack of agreement between the particular sequence in any two parts of the field finds at least a partial

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explanation in the vents. The largest vents in Bute, such as the Suidhe, Creag a Mhara, or Dunagoil, are pigmy structures compared, say, to Dungoyn, so that while extensive flows are natural in the Campsie Fells, in Bute the numerous (fifteen or twenty) small vents within a small area would give rise to lavas of very limited extension, the flows dying out rapidly or interdigitating with the flows of neighbouring vents. In those circumstances unless each and every vent were ejecting similar material at the same time to form uniform sheets over the area, it is hard to see how a sequence in one part of the field could be got to correspond with that in another part, even when the localities are chosen close together.

Pyroclastic Rocks.

These consist of agglomerate and tuff. The agglomerate, with the exception of a bed along the shore between Uamh Capuill and Uamh Phadaich, is confined to the necks, while the tuff occurs in beds ranging up to 6 feet in thickness, and in places these alternate with the early lava flows with fair regularity. One of these red ash beds from the shore north of Run-nan-eun Point was sliced, and found to be very sandy; in fact, it might be termed an ashy sandstone or sandy ash with equal truth. This points to some of the early lavas having been extruded under water. The dark green ash on the shore north of Port Leithne is very well exposed, and occurs in finely stratified beds cut diagonally across by the olivine-dolerite sill. The necks with agglomerate vary in size from those like Suidhe and Creag a Mhara to small pipes only a few yards in diameter. The composition of the agglomerate in the necks becomes very significant when considered in relation to the neighbouring lava flows, and as the necks have been small and the flows from each limited both in number and extent it is possible in many cases to allocate the flows to the parent neck. The Suidhe vent is almost entirely occupied by an intrusive plug, so the method is inapplicable in that case, but Creag a Mhara, though invaded at the base, is mainly agglomerate composed of blocks of lava similar to the associated flows. The material ranges from fine ash and small angular

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fragments up to boulders 6 or 8 feet across. Fragments of sendimentary rocks, sandstone, conglomerate, and pebbles of quartzite occur, but they are not common. The material in the neck just south of Hawk's Nib is much the same, but on its north-east face patches can be found containing baked cornstone, sandstone, and conglomerate boulders to the exclusion of igneous rock. Among the smaller necks cases occur which seem to indicate that one neck may only produce one type of lava; for example, associated with the flows of bostonite there is a small neck entirely composed of bostonite fragments, while the analcitised basalt occurring about 300 yards north-east of Port Leithne has also possessed a private neck. The cases cited deal with types not easily confused—"kenspeckle" rocks —so it is probable that the principle applies to other cases less easy to prove. The existence of this close relation between the necks of agglomerate and flows of lava raises a point in connection with the dunsapie basalts of the south end—no neck has been found containing agglomerate with boulders of dunsapie basalt, and it is considered highly probable that they are mainly intrusive. There is nothing in their field relations to demand an extrusive origin, and what evidence there is inclines the other way. They do not show vesicular margins; they are sometimes hummocky, and lack the regularity of a lava, as at Port na Caillich, and, when presenting a good escarpment, it may be out of harmony with the neighbouring lava escarpments, as at St. Blane's Church. On the west side of the island the necks most worthy of note are the two at Dunagoil, one at the head of the bay, and one at the farm. The neck on Dunagoil Bay pierces the sedimentary rocks, and stands as an isolated hill rising from them and out of contact with the lavas. It is the only neck on the island so situated. The agglomerate forming it contains a high proportion of ash and fine material, but large boulders are also common, and an intrusion of markle basalt occupies the southern part of its base. Both necks are remarkably rich in agates and chalcedony, and in the neck at the farm fine flesh-pink botryoidal chalcedony can be got lining cavities. The neck on the bay is shot full of veins of chalcedony and jasper, while small milky pebbles can be picked out of the amygdales and made

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to exhibit their agate banding by treating with sugar solution and charring with sulphuric acid. Jasper veins similar to those in the neck are continued in the sedimentary rocks on the shore across the fault, and though somewhat irrelevant it is interesting to note that the conglomerate there contains numerous worn pebbles of jasper, yellow and red, also pebbles of white and red unaltered sandstone, dark green cherts, a porphyritic lava very decomposed, and coarse red pegmatite, in addition to the usual suit of Highland rocks found in Old Red Sandstone conglomerates of the district.

Minor Intrusives.

The minor intrusive phase of Carboniferous igneous activity is well represented in the south end of the island, sills, dykes, and plugs being numerous. Of the sills the most important are a group of three on the west side of the island, north of Dunagoil. One occupies the north side of Dunagoil Bay, from the head of the bay to Barr Point, another occupies an exactly similar situation with regard to Lubas Bay, while a third, running north-west between Lubas and Largizean for over half a mile, forms a tall escarpment, which continues till it meets the sandstone cliff of the raised beach east of Lubas Port. These three occurrences have been formerly grouped with the lavas, and in the section at the south end of Lubas Bay the 20° dip of the sandstone, compared with the 10° dip of the "trap," together with the absence of intervening cornstone, is cited as evidence of the unconformity existing at the base of the lavas (Gunn, 1903, p. 55). However, the only evidence in support of these being lavas is that their escarpments strike in the same general direction as the lavas, and as that direction is mainly dependent on the directions of faulting and tilting, a fairly regular sill would naturally be affected in a similar way. What positive field evidence there is points to the masses in question being sills, and there is a section at Barr Point (see text figure) which proves the case incontestably for that particular mass. Here the base of the sill rests on the Old Red Sandstone, passes along the bedding, and then abruptly cuts across the stratification to a higher

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horizon before continuing again along the bedding. Further, no vesicular margins are got in these rocks, no ash nor agglomerate is present in association, and single, and not stepped, escarpments are the rule, so that, if lava, each area would require to be one flow, and the depth and extension would be exceptional for the district. Where the junction of these markle sills with the sandstone is exposed at Barr Point and Fort Dunstrone, the lower part of the igneous rock is found to have assumed a form very common in sills of considerable thickness. A margin, 6 inches to 1 foot thick, and very compact, has separated off from the main body of the sill. This probably represents the depth of rock initially chilled during the intrusion, and it is usually divided off from the mass of the sill by a continuous joint. On the shore at Fort Dunstrone this marginal layer is greatly altered at its contact with the sandstone. While the mass of the sill is of very coarse blue markle dolerite, with large glassy labradorite phenocrysts, the margin is a pale buff rock studded with opaque white felspar phenocrysts. It effervesces strongly with acid, and, under the microscope, although little difference is noticeable in ordinary light, between cross-nicols, minerals and structure are entirely obscured by calcite. The fresh unaltered rock of the sills is composed of very large labradorite phenocrysts set in a groundmass, in which felspar laths greatly predominate over magnetite. A little green serpentine, occurring mainly interstitially, is present, but no fresh olivine is found. The rock is charged with long needles of apatite to a degree not observed in any of the lavas, and this, coupled with the comparative scarcity of femic minerals, form the only distinguishing mineralogical characteristics (Pl. XXXVIII., Fig. 4).

Along the coast south of Barr Point a number of negative dykes occur in this rock. These are irregular shrinkage cracks, 1 to 4 inches wide, which have been filled with sand and fine material washed in from the surface of the sill. Some of them would pass muster as small dykes of fine-grained, compact igneous rock, but a thin section reveals their clastic nature, the rock being mainly quartz grains in a cement of the fine material washed off the igneous rock or ground off the walls by subsequent movements.

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Numerous small sills, 2 or 3 feet thick, occur in the sediments at the base of the lavas at Port Uisg, Creag a Mhara, and south of Hawk's Nib. At Creag a Mhara one sill just above high-water mark is a fresh markle, with spheroidal and columnar jointing, but usually the sills are soft, dull red, ashy-looking rocks in a very decomposed state. In thin section they are so much decomposed, and replaced by calcite, that little can be made out of them. They are altered olivine basalts composed of plagioclase, serpentine, and magnetite, and they are usually non-porphyritic.

Plugs.—Intrusive plugs filling the necks are not common, but the large vent of Suidhe Chatain is almost entirely occupied by an intrusion. It is a fairly fresh olivine basalt, tending to the markle type, and forms a steep conical hill, rising to 517 feet, the highest point in this part of the island. The rock is poorly exposed, and only in two places has a little agglomerate been observed, so it would appear that the plug occupies practically the whole site of the vent. Creag a Mhara is mainly agglomerate, and has been intruded in a complicated manner round its base. The south seaward face, below high-water mark, is occupied by a concentrically jointed intrusion of craiglockhart basalt, in which the olivine phenocrysts have been replaced by hæmatite, which shows bright red in the hand specimen (Pl. XXXVIII., Fig. 5).

Dykes.—The dykes of Carboniferous age are numerous in the sediments at the base of the lavas, and also in the Old Red Sandstone further north. It is only occasionally that one of those dykes is observed to cut the lavas. They vary in trend and thickness, but, generally speaking, may be described as impersistent dykes, 6 or 8 feet wide, and with a tendency to run in a north-easterly direction, practically parallel to the dykes of Kainozoic age.

A good series of these dykes is got on the shore at Kerrytonlia, north of Kilchattan, and in Stravannan Bay, on the opposite side of the island. The dykes are never so fresh as the lavas, and the type of rock mentioned in connection with the sills as altered olivine basalt is a common type. Other types resembling the different lavas occur, such as dykes of mugearite and markle basalt. An easily accessible dyke of the

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former type occurs on the shore south of Kilchattan Pier, while another cuts a neck of agglomerate next the composite sill on the shore south of Uamh Capuill. This dyke encloses a mass of agglomerate in its centre, and is veined with quartz and calcite, crystals of quartz almost bipyramidal being obtainable. At the north end of Stravannan Bay and at Kerrytonlia Point composite dykes are found. These are about 8 feet wide, and the one at Stravannan Bay contains three types of rock. The centre of the dyke is of coarse markle, 2 to 4 feet, the phenocrysts large and closely packed. On each side of this central core occurs a rock somewhat similar, but distinguished by a marked decrease in the number of the phenocrysts. The outside sheets, intervening between this and the country rock, are very fine grained, and at first glance seem non-porphyritic. Closer inspection reveals the presence of a fair number of phenocrysts, thin clear plates of felspar quite inconspicuous against the background of the groundmass, which in other cases throws up the white opaque rectangles of weathered labradorite. In places the junctions of the three different types of rock are so sharp that separate intrusions—probably from the same magma at short intervals—must be postulated to account for the multiple character of the dyke. A markle magma intrudes a thin 2-feet dyke into the sandstones, while the intra-telluric generation of felspars is weak in number and size of individuals. A little later a second intrusion with larger and more numerous phenocrysts is inserted along the central plain of weakness of the first, to be split in its turn by the third and last invasion, when the felspar phenocrysts have reached their maximum development. The Kerrytonlia shore shows the greatest variety of Carboniferous dykes in a short distance. They vary from coarse markle, through types with sparse or sporadic pink phenocrysts of felspar, to fine grained, greatly weathered olivine-basalts, and their north-east trend is very constant. The shore south of Hawk's Nib is an area intensely complicated by numerous dykes and irregular intrusions of this altered olivine-basalt, which bake and alter the sedimentary rocks till junctions become hard to determine. The intrusions here are very amygdaloidal with the amygdales filled with quartz and calcite.

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Intrusion Carrying Fragments of Plutonic Rocks.

This intrusion occurs on the shore at a point about 400 yards south of Hawk's Nib, and it contains a most remarkable series of rocks. The credit of its discovery belongs to Miss A. T. Neilson, of this Society. It pierces the sandstones, cornstones, and clays of Calciferous Sandstone age at a point a short distance north of where they are overlain by the Runnan-Eun lavas. The whole mass is no more than about 20 yards by 30 yards in extent, and most of it lies between tide marks. It is intruded into the sediments at a high angle, dipping to the south, and on the land side, a bar of sandstone divides it from another small area of the same rock, which is seen to disappear under the scree from the lava cliffs bounding the raised beach, so that the limits of this second part are uncertain. In spite of its very limited dimensions the mass on the shore has proved a veritable museum of basic and ultrabasic rocks, all of them new to the district, and many of them thoroughly plutonic in habit. It is probable that here at last occurs tangible evidence of uncovered masses of Carboniferous plutonic rocks, and the number and diversity of the samples present in this small area are phenomenal. The occurrence is either an intrusion carrying xenoliths or a neck subsequently invaded, but the former seems the more likely. The intruded rock is a much altered, amygdaloidal olivine-basalt of a type very similar to the dykes and irregular intrusions of early Carboniferous age, which are abundant a few yards to the north. The southern half of the intrusion, which is also the upper half, is practically free from xenoliths, but as the northern and lower half is approached xenoliths become so numerous and closely packed that the enclosing olivine-basalt is seldom in evidence.

It is not intended, in the present paper, to give a full account of the petrography of the rocks present in this occurrence, but it will be sufficient for general descriptive purposes to state the rock types already found. The xenoliths average about 4 to 6 inches in diameter, and a number of these have been found to be practically single mineral rocks, such as anorthosite, a labradorite rock (Pl. XXXVIII., Fig. 1); dunite, a fresh

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olivine rock (Pl. XXXVIII., Fig. 2); serpentine, a pale grey rock composed entirely of colourless serpentine; and pyroxenite, under which term are included augite rock, diallage rock, and hypersthene rock. Numerous rocks which are combinations of two or more of the different minerals named above have been found. For example, gabbro xenoliths are numerous, though the weathered condition of most of these contrasts strongly with the fresh state of the labradorite, pyroxene, and olivine in the single mineral rocks. Olivine-pyroxenite (Pl. XXXVII., Fig. 1), fresh and very tough, is one of the most common rocks present. To avoid a long list of rock names, olivine-pyroxenite can be understood here in its widest sense, as different pyroxenes occur, and the relative amounts vary. Types are got linking up pyroxenite, by a gradual increase in olivine, to pure olivine rock. In addition to the above formidable list of plutonic rocks, small blocks of various basalts are also found, including types, such as Hillhouse and Dalmeny, which have not been observed among any of the lava flows on the island. So far no fragment of any of the sedimentary rocks pierced by the intrusion have been found in it, although the pale grey serpentine looks exactly like a baked cornstone, and maintains the deception by effervescing strongly with acid. Large, fresh pieces of augite showing no good crystal faces are common, and these measure 1 inch or 2 inches across. These were noticed to be very similar to some augite specimens in the Hunterian Museum, which were collected by Dr. John Young from the Black Rock, Fairlie, and described by him in a short paper (1894, p. 13), so, acting on the possibility of the Black Rock holding further treasures, a short visit was paid to it. It resembles the Bute occurrence in some respects, and has yielded a fairly coarse biotite-pyroxenite not got in Bute so far.

The large number of different rock types occurring in an intrusion of such limited size seems difficult to explain, especially when one considers the distances that usually have to be covered to collect a variety of rocks in the field; but, when it is recognised that the rocks present are all basic and ultrabasic rocks, the problem of their presence in such variety

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becomes more easy. In a complex of plutonic rocks the acid rocks occupy large tracts of country, but basic and ultra-basic types may occur within a very small area. Though the plutonic complex of Loch Garabal occupies most of the country between the heads of Loch Lomond and Loch Fyne, the ultra-basic rocks occupy only a small proportion of the whole. Some of these rocks bear a strong resemblance to the Bute specimens, and thin sections of wehrlite (Wyllie and Scott, 1913, p. 502) from the two localities are indistinguishable. In describing the ultra-basic plutonic rocks of Skye Harker writes (1904, p. 422), "The most striking feature is extreme complexity of structure. The rock types represented range from troctolite, through picrite, to dunite, and even to seams of pure picotite; and these have been intruded in part simultaneously, so that they alternate in bands, in part successively, so that a later rock veins an earlier, or is crowded with débris from it." With different types of rock occurring in this manner, it is clear how even a small intrusion or neck might be found to contain a large variety of rocks after having been thrust through such an area. Thus the obvious inference to be drawn from the occurrence of this suite of ultra-basic plutonic rocks in Bute is that a mass of Carboniferous plutonic rocks lies buried at no great depth under the Firth of Clyde and adjacent land; and, as the phase of minor intrusives follows the plutonic phase in a cycle of igneous activity, this particular minor intrusion in Bute must have traversed part of the ultra-basic plutonic area before reaching its present position.

Petrography.

Trachytes or Bostonites.—At least three flows of this lava occur, and an associated neck of bostonite agglomerate. Similar rocks are present in Cumbrae and other parts of the Clyde area, but occur as minor intrusives, whereas in Bute bostonite is found only among the lavas. The flow of widest extent stretches from North Garrochty to the sea at Port Luchdach, and two slices from this flow have already been described in the Memoir of the Geological Survey (Seymour, 1903, p. 176). The other flows occur, one overlying the

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olivine-dolerite sill at Port Leithne and the other at Uamh Capuill, where part of the flow has been partially enclosed by the composite sill. In the hand-specimen the rock varies from a reddish colour to a light grey with occasional pink felspar phenocrysts showing in the banded groundmass. The beach pebbles of this rock develop a very smooth surface, which exhibits to advantage the dark flow lines and red phenocrysts, and gives the rock a handsome appearance not apparent in the rough. Hand-specimens taken from the flow east of Loch-na-Leigh have all the appearance of agglomerate, but this is due to irregular staining with hæmatite, as thin sections show felspars passing from one pseudo-rock-fragment to another of lighter tint. The rock is composed of a felt of orthoclase and albite laths with small cubes of magnetite, enclosing phenocrysts of albite and orthoclase few in number but large individually and tending to group. Interstitial quartz is present in varying proportions, the bostonite from Port Leithne containing considerably more than either of the others. Scattered through the ground-mass of the Port Luchdach bostonite occur minute grains of a pale green mineral, probably soda pyroxene. All examples are holocrystalline, and show well the parallel orientation of the felspar laths.

Mugearites.—In Bute typical mugearites are not abundant, but basaltic mugearites and transition types approaching microlitic jedburgh basalts are common; porphyritic types, passing into markle basalts, are also of frequent occurrence. The presence of transition types makes the field diagnoses of mugearites somewhat unreliable, and the pale weathering tints and platey structure have not been found trustworthy criteria. In fact, without a thin section it is not easy to distinguish mugearites from jedburgh basalts. The best development of mugearites occurs in the Creag a Mhara lavas. In thin section they are found to be composed essentially of straight-extinguishing felspar laths with cubes and irregular patches of magnetite set in a groundmass of weathered felspar and pale-green decomposition products. Olivine is never present in a fresh state, but is represented by occasional areas of serpentine of irregular outline. Needles of accessory apatite are fairly numerous in some slides. The mugearites are seldom

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fresh, and usually yield unsatisfactory slices, but the specimen figured (Pl. XXXVI., Fig. 1) is an exceptionally fresh rock.

Markle Basalts.—These are more numerous than any other type of lava in the area, and among the minor intrusives they likewise bulk most largely. They vary unaccountably from fresh, blue, compact basalts with glassy phenocrysts of labradorite to dull grey, weathered types with white opaque felspars. Vesicular and amygdaloidal varieties are common, and the weathering of the margins between two such flows often simulates an intervening bed of tuff. In thin section the markles are seen to consist of large plagioclase phenocrysts, often labradorite, with occasional serpentinised olivines set in a groundmass which varies from holocrystalline to glassy and microlitic. In a slaggy lava from Run-nan-Eun the groundmass consists of microphenocrysts of felspar and several sizes of microlites, many with bifid terminations set in a continuous dark glass, while in another Run-nan-Eun markle the groundmass consists of a holocrystalline aggregate of felspar laths, magnetite cubes, and euhedral grains of augite. The appearance of sporadic augite among the phenocrysts produces types linking the markles with dunsapie basalts, but though such are common among the Ambrisbeg lavas, they are scarce in the south end of the island. The markle basalts, more than other types, have undergone the process of albitisation (Bailey and Grabham, 1909), and among them every stage leading to complete albitisation can be observed. Few have escaped entirely, others show only cores and isolated patches of albite in the labradorite phenocrysts, while others have had the phenocrysts entirely replaced and even the groundmass attacked. In the slaggy markle referred to above, the felspar phenocrysts are large and abundant, a few are simply twinned and extinguish straight (presumably orthoclase), while all the others have been completely replaced by albite.

Jedburgh Basalts.—These are almost as numerous as the markles and, like them, occur at all horizons. Their greatest development occurs among the Glen Callum lavas, low down in the series. Both ophitic and microlitic types of jedburgh basalt are represented, but the typical ophitic jedburgh is scarce. It contains micro-phenocrysts of labradorite and ser-

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pentinised olivine in a groundmass of magnetite grains and felspar laths in ophitic relations with augite. In patches a pale brown glass occurs in place of the augite, filling the interspaces and enclosing the felspar and magnetite. The microlitic varieties of jedburgh basalt differ from the foregoing in having the augite present as subhedral grains instead of microophitic plates. This type is by far the more common, and passes imperceptibly into basaltic mugearite.

Dunsapie Basalts.—The basalts of dunsapie type are usually very fresh, dark blue rocks, with only a very thin skin of buff-coloured, weathered material. The black augite phenocrysts against this buff background enable this type to be easily identified in the field. In thin section the rock has a fine appearance (Pl. XXXVIII., Fig. 6), especially when the olivine phenocrysts have been replaced by red-brown pleochroic iddingsite. There are two generations of all the phenocrysts. The felspar is fresh labradorite, sometimes perfectly clear and at others packed with inclusions of magnetite cubes and augite laths. The augite phenocrysts are not so numerous as the others, nor do they present such regular boundaries, being frequently misshapen and eaten into by the groundmass. They are of a pale purple variety, but sometimes the purple hue is confined to the margins, while the central portions of the crystals are almost colourless. There are two generations of magnetite, one comparable in size with the micro-phenocrysts of the other minerals, while the other occurs in the groundmass which is a holocrystalline, granular aggregate of felspar, augite, and magnetite. In the dunsapie of Port na Caillich the olivine phenocrysts are entirely replaced by rich brown iddingsite, but in the dunsapie from the Cauldron the olivine is fresh, except for thin, serpentine linings to cracks.

Craiglockhart Basalts.—In the hand-specimen all the basalts of this type except the intrusion at Creag a Mhara are soft and weathered, resembling dull red tuffs rather than lavas. Of the lavas, the flow overlying the ash beds at Port Leithne is the least altered. It contains both micro- and macrophenocrysts of augite and olivine; the augite is fresh and faintly purple, and the phenocrysts tend to gather in clusters; the

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olivine is never fresh, but is replaced variously by hæmatite, iddingsite, and serpentine. The groundmass is made up of laths of plagioclase, small augites with sub-ophitic tendency, and cubes of magnetite set in a pale green isotropic base, probably a chloritic decomposition product.

Analcitised Basalt.—This rock is represented by a neck of agglomerate and associated lava occurring on the shore next the olivine-dolerite sill, 300 yards north-east of Port Leithne. In the hand specimen it resembles a markle with a compact, cherty-looking groundmass; in colour it is dark green in patches, and it has a general greasy or waxy appearance. It contains two generations of labradorite phenocrysts, some clear, others full of inclusions, and all more or less albitised. There are also large phenocrysts of augite, and the unaltered parts of these show them to be a pale colourless variety. The groundmass is composed of laths of felspar, cubes of magnetite, and indeterminate brown grains, either glass or decomposition products of augite grains. In addition to the albitisation of the felspar phenocrysts, the rock has been greatly analcitised. The augite phenocrysts have suffered most heavily from the analcitisation; some of them are completely replaced, while the least altered among them can show no more than a marginal fringe enclosing a few islands of unchanged augite, all the rest having gone to analcite. The analcite pseudomorphs (Pl. XXXVI., Fig. 2) are frequently rendered dark and opaque by hosts of inclusions of ægirine-augite prisms, but these usually occur round the margins and along definite lines into the interior, thus marking off areas of water-clear analcite. From the dark lines small prisms of ægirine-augite protrude into the clear analcite, and with the high power can be individualised from the mass. Analcite has also replaced many of the small felspars of the groundmass, and veinlets of analcite penetrate the rock, breaking across felspar phenocrysts, and displacing the halves in a way that shows the analcitisation to be subsequent to the consolidation of the rock. The small analcite veins have the same opaque margins and clear interiors, into which the inclusions project. In addition to these small included prisms of ægirine-augite, that mineral is also formed

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by direct alteration of the augite phenocrysts. Where the phenocryst is crossed by a vein of analcite it is found to pass insensibly into the green variety, and that portion of the crystal is distinguished from the unaltered augite by its intense pleochroism, lower extinction angle, and lower double refraction. At other times augite is replaced by the formation of little green prisms of ægirine-augite regularly arranged in parallel rows, the direction of the rows being apparently determined by the cleavage in the original augite crystal. The rock seems to have been a macro-porphyritic basalt with phenocrysts of augite and plagioclase. This is Type III. of the seven possible types indicated by Mr. Tyrrell (1912, p. 231), and it is a type that awaits a name. However, it is not considered advisable to name the type from this Bute occurrence, as its development is so limited and the rock is so heavily analcitised. The alteration of phenocrysts is sometimes so complete that there is a possibility of olivine having figured as a phenocryst originally, in which case the rock would merely be an analcitised dunsapie basalt. If olivine phenocrysts were ever present the analcite must have attacked them preferentially, and removed all trace of them. However, it is certain that no proved dunsapie on the island has been observed to show similar phenomena of analcitisation, and this fact rather strengthens the probability of the rock being a new type.

Petrology.

A study of the morphology of the Bute lavas makes it clear that Bute must have formed the northern limit of the Clyde Plateau. The necks are numerous and small, flows are thin and limited in extent, and it is highly improbable that the main mass of lavas of the south end of the island were ever continuous with the small outliers to the north. No necks pierce the intervening miles of Old Red Sandstone, and none of the necks or flows in the lava areas suggest power to link up the different districts; so that the conclusion is come to that those outliers are not merely outliers of denudation, but outliers from the Carboniferous vulcanicity lying off the north-western margin

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of the plateau. The phase of minor intrusives is well represented by dykes, sills, and plugs of essentially the same rock types as occur among the lavas, and among the reputed lavas it is not impossible that unproved sills occur, the basalts of dunsapie type being specially suspect in this connection. One notable minor intrusion carrying a suite of basic and ultrabasic plutonic rocks indicates the presence and proximity of rocks of the abyssal phase of Carboniferous igneous activity, and gives the first definite evidence of the types of rock constituting the plutonic complex.

ANALYSES AND NORMS

		I.*	II.†	III.*	IV.*
	SiO_2	50·24	61·19	66·60	51·45
	TiO_2	3·09	1·83	·55	·93
	Al_2O_3	15·01	14·20	12·95	15·54
	Fe_2O_3	8·94	8·08	7·25	4·87
	FeO	6·46	2·49	·83	6·06
	MgO	3·16	·50	·76	5·91
	CaO	5·61	1·74	1·41	8·69
	Na_2O	3·47	6·64	6·14	2·82
	K_2O	1·91	1·80	3·10	1·94
	P_2O_5	—	·08	—	—
	H_2O	(+)1·77 (−)1·05	1·58	(+) ·46 (−) ·49	(+) 1·19 (−) 2·14
		100·71	100·13	100·54	101·54
S	Quartz,	8·16	12·60	17·16	2·10
S	Orthoclase,	11·12	10·57	18·35	11·12
S	Albite,	28·82	56·07	48·73	23·58
S	Anorthite,	20·02	3·61	—	24·19
F	Diopside,	6·05	3·23	4·10	16·03
F	Wollastonite,	—	·23	·70	—
F	Acmite,	—	—	2·77	—
F	Hypersthene,	5·10	—	—	12·20
F	Magnetite,	11·60	2·78	2·55	7·19
F	Ilmenite,	5·93	3·50	1·66	1·67
F	Hæmatite,	·96	6·24	4·48	—
F	Apatite,	—	·34	—	—
	S/F Ratio,	2·29	5·08	5·18	1·64

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† Anal. A. Stevens, Esq., M.A., B.Sc.

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	Rock.	Locality.	Magmatic Symbol.
I.	Mugearite.	Second Lava Flow, near "R" in Reservoir, Creag a Mhara Lavas.	II., 5, 3, 4. *Andose.*
II.	Bostonite.	Lava enclosed by Composite Sill, Cave, Uamh Capuill.	II., 4, 1, 4. *Pantellerose.*
III.	Bostonite.	Lava, Loch na Leighe.	II., 4, 1, 4. *Pantellerose.*
IV.	Xenolithic Quartz-Dolerite.	Kainozoic Composite Sill, Glen Callum Bay.	III., 5, 4, 3. *Auvergnose.*

The lavas and minor intrusives constitute a series which ranges from bostonites, at the acid end, to craiglockhart basalts, at the basic end, and those two end types are linked up by intermediate rocks giving practically a continuous series. The mugearites, markle, and jedburgh basalts are intimately connected by numerous insensible gradations, and markle basalts pass imperceptibly into dunsapie types by the appearance and increase of augite phenocrysts. The most pronounced gaps in the series occur next the two end members; no intermediate types have been found to connect dunsapie with craiglockhart, and the same applies to mugearite and bostonite. A type of mugearite composed chiefly of oligoclase laths and magnetite (Pl. XXXVI., Fig. 1) approaches most nearly to the bostonites, and resembles them strongly in thin section. However, an analysis of a rock of this type (for which I am indebted to Mr. J. V. Harrison) shows that chemically there is still a considerable gap between this rock and the bostonites, especially in the silica, lime and the alkalies. The variation among the bostonites themselves is evident from thin sections, analyses, and norms. This consists chiefly of variation in free quartz and albite present, but how much of this is an original difference, and how much is due to silicification and albitisation it is impossible to say. An interesting point is brought out by

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the norm of III., the bostonite from Loch na Leighe; the norm shows 2·77 per cent. of acmite, while II. contains none, and the thin section of III. shows in the groundmass numerous small green prisms of soda pyroxene, which are absent in II., so that in the case of those two bostonites the norms are comparatively modal.

Among the markle basalts, jedburgh basalts, and mugearites the field association is so intimate, and thin sections show every shade of gradation, linking up the three types, that it seems possible to connect the three immediately with the same magma without postulating separate magma reservoirs, and to ascribe the differences to physical differences of crystallisation and extrusion. In the thin sections of these rocks for every one that falls naturally and easily into a type there are several that are only named after weighing up the characteristics of the three types, and hesitating as to which has the greatest claim to the name. In this connection the composite markle dyke of Stravannan Bay is of peculiar interest. Going on the justifiable assumption that the three intrusions into this dyke were from the same magma, and represent progressive stages of intra-telluric crystallisation, then the first intrusion giving the marginal sheets of the dyke only required to be a little earlier to be classed as a basaltic mugearite or a microlite jedburgh basalt, and increase in size and proportion of felspar phenocrysts gives the transition into typical markle basalt.

Albitisation and Analcitisation.—Among the Bute basalts examples of all stages of albitisation are common, and the process has gone on in the manner described by Bailey and Grabham (1909, p. 250). The more basic plagioclase felspars of the more acid lavas have been attacked, while the felspars of the more basic types, such as dunsapie basalts, have been untouched. Mr. Tyrrell (1912, p. 243), in remarking on albitisation, notes the field association of that phenomenon with the presence of zeolites, and suggests a connection between the two; but in Bute, except for a little stilbite in the necks, zeolites are absent, and jasper, agate, and calcite are the most common occupants of cavities. Analcitisation is an analogous process to the albitisation, and in the analcitised basalt described the two processes have gone on side by side. The

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analcite replaces the felspar in patches, and breaks across the twinning in thin ribbons, like a diagram of step faulting. While albitisation attacks by preference the more basic felspars of the affected rock, analcitisation singles out the ferro-magnesian phenocrysts in preference to the felspars. The felspars can only show small patches and ribbons of analcite replacement working along cracks and solution planes, but many of the other phenocrysts have been completely removed and replaced by analcite (Pl. XXXVI., Fig. 2). While the lime of the original lime-soda felspar has often been completely removed by albitisation, it is interesting to note that the ferro-magnesian silicates removed by the analcite have had soda added to the molecule, and have been redeposited as numerous minute prisms of ægirine-augite clouding the analcite pseudo-morphs. In all probability the process of analcitisation like that of albitisation occurred after the solidification of the rock, and during the cooling. At this time a very appreciable percentage of soda must have been added to the rock by the soda-rich solutions performing the analcitisation and albitisation.

Minerals in the Lavas.—In addition to the minerals already mentioned as common in the lavas, there is an occurrence of garnet, lining vesicles in a mugearite, which is noteworthy on account of its rarity. The mugearite occurs on the shore of Run-nan-Eun abutting against the north side of the large olivine-dolerite sill. It is very vesicular, with the vesicles drawn out into ellipsoids in the direction of the flow. Many of the vesicles are filled or lined with delessite, but others occur lined with a topaz-coloured layer of garnet crystals in rhombic do-decahedra. In colour the garnets are a greenish yellow, and are presumably grossularite or andradite, or, what is more probable, an isomorphous mixture of those two molecules. Garnets in eruptive rocks were recorded by Cross (1885); these were spessartite, occurring in lithophyses in rhyolite, and were considered to be of primary origin and produced by sublimation. In the Bute occurrence the garnets can be added to the albite and analcite as pneumatolytic minerals formed during the cooling of the lava. In the same lava, pipes and irregular dyke-like masses of pale pink

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rock like trachyte occur, but these prove to be only altered portions of the mugearite flow they occur in, and the alteration may be due to the same pneumatolytic agents. In these Run-nan-Eun lavas finely-coloured agates, with centres of crystalline quartz, occur, and banded jaspers up to 1 foot in diameter are fairly common. Jasper also occurs in veins and in irregular masses with ill-defined borders shading into the enclosing lava. On the suggestion of Professor Gregory that these might be formed by metasomatic replacement, a section of one was cut, and among the jasper small areas of the original lava were got, showing where the replacement had been incomplete.

Permo-Carboniferous Rocks.

The igneous rocks of this period consist of —

(1) Thick east and west dykes of granophyric quartz-dolerite.

(2) A small drumlin-shaped intrusion of quartz-dolerite east of Lubas.

(3) A large olivine-dolerite sill crossing the south-east corner of the island, a small olivine dolerite intrusion on the shore north of Uamh Pharaich, and a few dykes and small sills. One of the small sills of olivine-dolerite contains veins of tachylyte.

The East and West Dykes.—Two of these cross the island as thick, persistent dykes, one stretching between the south end of Ettrick Bay and the centre of Rothesay Bay, and the second running parallel about 1 mile to the south. As might be expected with this rather universal rock, it is found to differ in no essential from other examples already fully described (Tyrrell, 1909). However, at Bogany Point an east and west dyke, which may be part of the second dyke referred to above, is worthy of note on account of the way it is cut by a Kainozoic dyke. The north and south dyke cuts right across the quartz-dolerite, giving chilled margins which can be followed as wavy, irregular lines from one side of the older dyke to the other. In spite of the large numbers of dykes at different directions it is seldom that a

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crossing is got unequivocally exposed as this one is. It is just at this point that the mineral spring occurs, and the right angle enclosed by the crossing dykes may have determined its point of emergence.

Fully half a mile east of Lubas Bay there is a small grass-covered intrusion of quartz-dolerite forming a low, round-backed ridge which runs east and west for about 400 yards before shading into the country on either side. In the hand-specimen the rock resembles a dark blue basalt, but the thin section shows it to be a quartz-dolerite of unusual type. It is a fairly coarse-textured aggregate of quartz, plagioclase, chlorite, magnetite, and apatite. The large decomposed chloritic areas show no structure to indicate the original mineral unless the indefinite way in which they enclose the felspars at times can be regarded as indicating ophitic structure of an original pyroxene. The felspar is an andesine-labradorite, fairly fresh, and it is the most abundant constituent. Quartz occurs next in order of abundance, and it does not occur chiefly in micropegmatite as in the east and west dykes, but in fairly large plates, filling interspaces and enclosing the other minerals like quartz in granite. Magnetite is plentiful in idiomorphic cubes, and apatite needles are so numerous, especially in the quartz, that they must form an appreciable proportion of the rock. In some of the interspaces among the felspars micropegmatite is got in place of quartz, and occurs both in rod-like and triangular intergrowths. This rock is related to the quartz-dolerite of the east and west dykes, but differs in the large excess of free quartz, while its occurrence in the field contrasts strongly with the persistent nature of the large east and west dykes running unbroken for miles across country.

Olivine-Dolerite Sill.

This large Permo-Carboniferous sill stretches practically across the south end of the island in a south-easterly direction. It rises from the sea about a quarter of a mile north of Runnan-Eun Point, and, dipping at first in the same direction as the lavas, but at a slightly higher angle, it rises obliquely up the lava cliff, its boundaries being apparent from a distance

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by its distinctive soft brown weathering. Crossing the lavas of Run-nan-Eun, and making no prominent topographical feature, it descends to Glen Callum, where it is broken and displaced by the fault. Rising on the south-west side of the glen, it has thickened much beyond its original 20 or 30 feet, and forms a steep cliff with perched blocks. The peculiar rich-brown soil of its weathering, from which weathered spheroids protrude, renders its outcrop visible from Run-nan-Eun Point, a distance of nearly half a mile (Pl. XXXV.). After rising to a height of 485 feet in Torr Mor, it turns south and is abruptly truncated by the later Kainozoic composite sill. It is not observed again till it is got lying at a low angle and occupying all the ground between the composite sill and the shore at Port Leithne. It may have a continuous outcrop between this and Torr Mor, but with the exception of a slight hollow south of its crossing with the composite sill there is no evidence of it. On the shore north-east of Port Uisg it dips down under the ash beds, crossing them obliquely in a flat inclined plane, whose upper surface shows the chilled margin excellently. The innumerable joints intersecting the surface and marking off the ends of the miniature columns of the chilled rock give it a strong resemblance to a tessellated pavement. South of Barr Buidhe the boundary of the sill is indefinite and unsatisfactory to trace, but across the Port Uisg fault the olivine-dolerite stands out as a hard part, and forms quite a well-marked feature on the shore and raised beach. The rock composing this sill weathers more easily and deeply than any other igneous rock in the district. In places it can be crumbled with the hand, and in such a place, on the shore at Run-nan-Eun, the increased richness of the grass bordering the path where it crosses the sill testifies both to rapid weathering and richness of soil produced. As may be inferred, getting through the weathered zone to procure the fresh blue rock within involves operations approaching the borderline between geology and quarrying. The jointing divides the rock into large cuboidal blocks, and when horizontal joints are numerous very typical mural jointing is produced.

In thin section the fresh rock is a coarse ophitic olivine-dolerite composed of titaniferous magnetite, slightly serpen-

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tinised olivine, and pale purple augite in ophitic relations to the labradorite. In spite of the considerable area occupied by this sill the rock is monotonously uniform, and the only variation found, in addition to chilled margins, is a type of lighter colour and coarser texture, which occurs in veins and tongues 1 or 2 inches across. These weather out as hard parts, and fragments can be easily picked out from the weathered dolerite. In thin section it is seen to be a very fresh rock (Pl. XXXVI., Fig. 4), just a coarser replica of the ordinary dolerite, and it shows the ophitic structure to perfection. The olivine is fresh, and seems to have crystallised about the same time as the augite, as it also poecilitically encloses the felspar. Filling the little triangular spaces enclosed by sets of three felspars, clear analcite occasionally occurs, so that this final product of consolidation of the dolerite magma has affinities with the crinanites (Tyrrell, 1913, p. 307).

In addition to the large sill there are several smaller intrusions of the olivine-dolerite, which seem to be Permo-Carboniferous in age rather than Kainozoic. In thin section there is nothing to distinguish the olivine-dolerites of the two periods, but in the field the weathering of the large sill contrasts strongly with the olivine-dolerite dykes of undoubted Kainozoic age. In the Kainozoic dykes the weathering is only skin deep, and thin splinters from a weathered surface usually reveal fresh blue-black dolerite on the new fracture. When some dykes behave in this way and others weather deeply, like the dolerite of the sill, the most feasible explanation is that these latter are also Permo-Carboniferous in age. Such a dyke occurs on the shore 100 yards north of the olivine-dolerite sill at Run-nan-Eun, and running south, penetrates the sill, passes under the lava scree of the raised beach cliff, and emerges on the shore east of Run-nan-Eun Point. It is conveniently situated for comparison with the large sill.

Fifty yards north of this dyke a small impersistent sill of similar rock, 2 or 3 feet thick, pierces the lavas. It is a finer-grained olivine-dolerite, and is noteworthy on account of veins of tachylyte, which penetrate it and are continued into the overlying lava (Pl. XXXVII., Fig. 2). The veins are about half an inch thick, and make equally sharp junctions with the

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dolerite sill and the enclosing lava, so that they have been injected after the sill has solidified and cooled. This mode of occurrence as rapidly-cooled veins of residual magma penetrating both sill and country rock is peculiar, for in the tachylytes studied by Professors Judd and Cole (1883) the only mode of occurrence found in the West of Scotland was as rapidly-cooled selvages to basaltic dykes. The rock is a dense black glass with conchoidal fracture, opaque even in thinnest splinters, and yielding a powder which is strongly magnetic. In thin section the rock is found to be porphyritic with fresh acicular labradorite felspars, occasionally in groups, but usually as single crystals sparingly sprinkled in a black opaque glass. A second generation of small bifid microlites is present. A few regularly bounded yellow areas pseudomorphs after augite or olivine are the only other crystals present. The glass is black and opaque even at the edges of the slide, but under favourable circumstances, say, where a felspar occurs partially beneath the surface of the slide, and so covered only by an exceedingly thin film of the glass, the dense black is found to give way to reddish brown. In this are seen some scarcely resolvable spherulites, small areas lighter in colour and circular in outline. When closely packed their interference produces polygonal shapes like honeycomb. In reflected light the dark opaque mass of the glass is seen to contain numerous lighter-coloured patches of hazy, indefinite outline, reminding one of the groups of feathery microlites in Arran pitchstones. These may be due to the decomposition of feathery growths of titaniferous magnetite.

Kainozoic Igneous Rocks.

These consist of a composite sill and numerous dykes and inclined sheets of dolerite. The composite sill has been described in detail (Smellie, 1913), and will only be mentioned here. It is composed of five sheets, a thick central core of hypersthene-dolerite flanked by two sheets of quartz-oligoclase-porphyry, each of which has a thin sheet of dolerite interposed between itself and the country rock. The dolerite has been intruded first, and carries xenocrysts of quartz and oligoclase

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picked up from the quartz-porphyry magma prior to intrusion. The quartz-porphyry, intruded along two planes of weakness in the dolerite, carries xenoliths of that rock picked up during intrusion. At one point, about 400 yards north-west of Roinn Clumhach, the acid magma has pushed out beyond the protecting dolerite, and the consequent rapid cooling has produced a pitchstone-porphyry. The sill rises from the sea at Roinn Clumhach, runs north-west nearly to Torr Mor, where it turns abruptly and crosses the island to re-enter the sea at Uamh Capuill.

The dolerite dykes of Kainozoic age are very numerous, and are distributed over the whole island. They are usually about 8 or 10 feet thick, but range down to 1 or 2 feet, while in the north end of Bute dykes of 30 or 40 feet in width occur. One such occurring between Port-Bannatyne and Ettrick Bay is quarried for road metal. Another thick dyke is quarried at Crossbeg, south of Loch Fad, and it is noteworthy as a locality for good crystals of dog-tooth spar, which occurs in veins and pockets between the dyke and the conglomerate into which it is intruded. The Kainozoic dykes trend north and south, or north-north-east, but very occasionally dykes are met with which do not follow either of those directions. At the south-west end of Loch Fad a dyke of ophitic olivine-free dolerite occurs, and it runs east and west. No instance of crossing between those dykes has been observed, so that nothing can be inferred as to the relative ages of the two sets. In the hand specimen they are even-grained, blue-black dolerites, the grain varying with the thickness of the dyke and the distance from the margin. Under the microscope they are seen to be of two kinds, olivine-dolerite and olivine-free dolerite. The olivine dolerites are composed of labradorite felspar, augite, olivine, and magnetite, and the texture varies from coarse ophitic types through rocks, with augite partly sub-ophitic partly granular to types completely granulitic in Judd's sense. The olivine, usually in clear, fresh grains or misshapen plates, may be equal in amount to the pale brown augite, but a decrease in the amount of olivine gives a gradual transition into the olivine-free type. Some of the rocks in which olivine is scarce or absent show no other difference from the olivine-

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bearing rocks, but usually the olivine-free dolerites have a distinctive texture, two grades being got in the one rock. The thin section shows an intimate mixture of a coarse and fine texture, the coarse with large felspars and cubes of magnetite ophitically enclosed by plates of augite; intermingled with this occur patches in which the felspar is in fine microlites, and the magnetite in very small cubes or drawn out into dark lines, and these are set in a groundmass of brown material, at first mistaken for augite plates, but found to be almost isotropic, and charged with another generation of microlites, seen only with the high power (Pl. XXXVIII., Fig. 3). This type has been got in both north and south dykes, and dykes with north-north-east trend. In addition to the dolerite dykes, which are more or less vertical, there is a number of inclined sheets or sills. These tend to occur where the course of the dyke is parallel or nearly so to the strike of the sandstones, in which circumstances the sheet tends to accommodate itself to the bedding planes of the sedimentary rock rather than rise vertically. In such cases the baking of the overlying bed of sandstone causes it to weather up as a hard part overhanging the space from which the sill has weathered. Apart from field occurrence, these inclined sheets do not differ from the dolerite of the dykes. A good example of a Kainozoic dolerite sill occurs on the shore about 200 yards south of Hawk's Nib. It dips south-west, and passing up from the sandstones and cornstones on the shore, cuts through the base of the large neck of agglomerate on the raised beach, and continues in a north-westerly direction into the lavas.

Tachylyte.—Running off the north-west corner of the map a north and south dyke is shown on the shore. Where the northern end of this dyke meets the sand of Stravannan Bay the width of the dyke has decreased to 2 or 3 feet. In the last 10 feet of the dyke, just before it loses itself in the beach sand, veins of tachylyte are got coming up the central plane of weakness, common in dykes of this thickness. The veins are numerous and irregular, varying from an eighth to a half inch thick of black glass, as perfect as obsidian. In places these perfectly glassy bands are merely selvages to small dykelets of tachylyte 1 or 2 inches thick, the central portions of

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which are porphyritic and dull black instead of shiny. In thin section the tachylyte is seen to be an opaque black glass, like the tachylyte already described from Run-nan-Eun, but it differs in the phenocrysts and in their distribution. The shiny black selvages are free from phenocrysts, but towards the interior of the tachylyte dykelet well-formed crystals of felspar, augite, and, very occasionally, olivine are got, set in a plentiful base of dark glass, which sometimes becomes less opaque round the phenocrysts, and shows its colour to be reddish brown. The large parent dyke is an ophitic dolerite carrying a few serpentinised olivines; and, presuming the tachylyte represents a stage in the attainment of that structure, it abundantly bears out Fenner's contention (1910) that ophitic structure represents an eutectic of the minerals involved. The augite and felspar have crystallised at the same time, and these minerals occur continually in pairs and groups surrounded by the glass. The stage at which magnetite crystals form has barely been reached ere the tachylyte solidified, unless a few feathery growths and the opacity of the glass are to be attributed to the separation of magnetite dust. In the glass, by reflected light, regular shapes much darker than their surroundings can be made out. They are shaped like felspar laths, and in some cases are seen to be continuations or completions of light, transparent felspars. In the Run-nan-Eun tachylyte felspar is practically the only mineral crystallised out (Pl. XXXVII., Fig. 2), so there has evidently been an excess of felspar over that required for the eutectic ratio.

Faults.—The faults have already been mentioned in other connections, and it only remains to state their age. As can be seen from the map, they break and displace all rocks older than Kainozoic, but the Kainozoic dykes and composite sill cross them unmoved. Thus the faulting is probably early Kainozoic in age. The faults are easily proved and located on the shore at their southern ends, but inland they probably die out, and towards their north-western ends their position and existence become matters of doubt.

I have to express my indebtedness to many friends, members of this Society, who frequently gave me their company during week-ends in the field. For the photographs forming the

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panorama shown in Plate XXXV. I have to thank Mr. J. W. Reoch, and for assistance with the photomicrographs I am indebted to Mr. J. V. Harrison and Mr. D. I. Russell. Before closing I would like to bear testimony to the excellence of the mapping of the rocks in the area (1-inch sheet, No. 21) shown in the Geological Survey Sheet 21. What differences have appeared in the present work are differences of interpretation or differences of addition, or differences of choice in doubtful boundaries, but having put the map of the area to the test during the field work connected with this paper, I finished with a well-founded respect for the mapping of Mr. Gunn. In conclusion, I have to express my own and the Society's thanks to the Carnegie Trust for generously providing a grant for the illustrations connected with this paper.

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EXPLANATION OF PLATES.

PLATE XXXVIII.

FIG. 1.—Anorthosite, labradorite rock, xenolith in intrusion carrying plutonic rocks. From the shore, 400 yards south of Hawk's Nib, South Bute, x 10. x nicols.

FIG. 2.—Dunite, olivine rock. From the same locality as Fig. 1, x 20.

FIG. 3.—Markle Basalt. From composite dyke, shore, north side of Stravannan Bay, x 20.

FIG. 4.—Coarse Markle Basalt showing albitised labradorite phenocryst. From large sill a quarter of a mile west of Largizean Farm, x 20.

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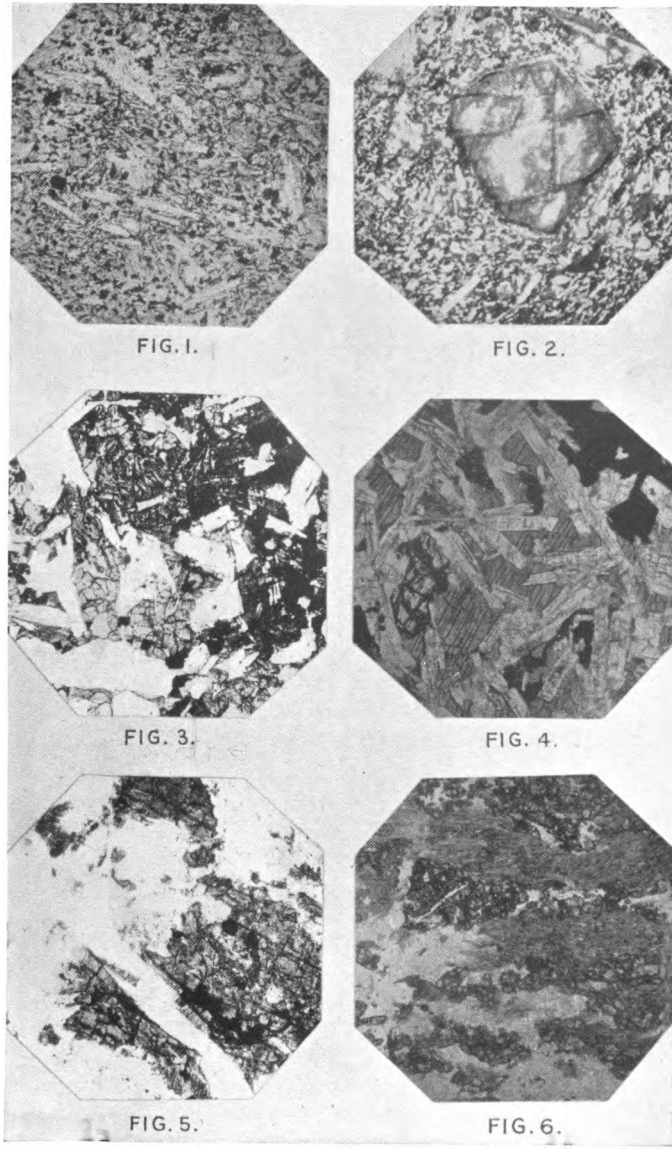

Photomicrographs of Rocks from Bute.

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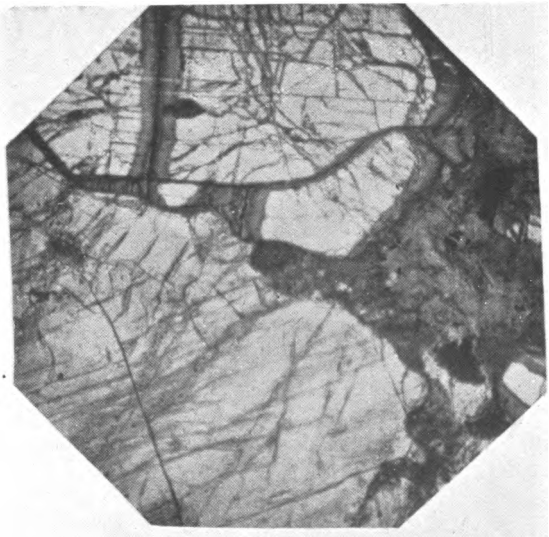

FIG. 1.

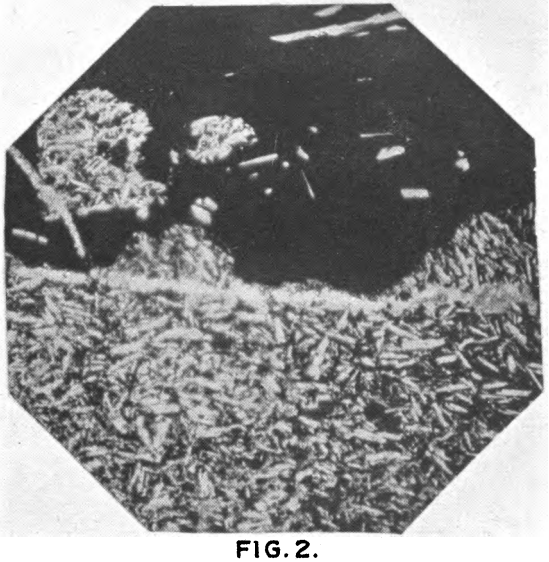

FIG. 2.

Photomicrographs of Rocks from Bute.

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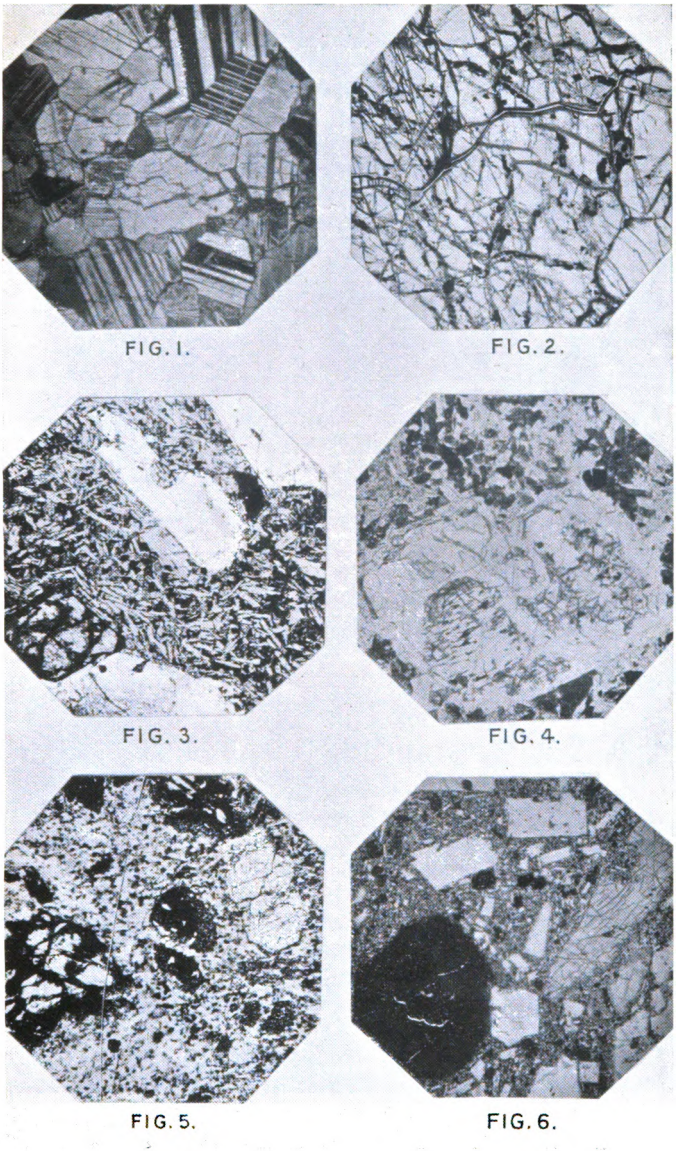

FIG. 1. FIG. 2.

FIG. 3. FIG. 4.

FIG. 5. FIG. 6.

Photomicrographs of Rocks from Bute.

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FIG. 5.—Craiglockhart Basalt, showing phenocrysts of augite (basal section) and olivine, the latter partially replaced by hæmatite. From intrusion into south seaward face of Creag a Mhara vent, x 20.

FIG. 6.—Dunsapie Basalt, showing augite phenocryst embayed by groundmass, phenocrysts of fresh labradorite, and red-brown pleochroic iddingsite (dark mass), a pseudomorph after an olivine phenocryst. From Port na Caillich, x 25.

PLATE XXXVI.

FIG. 1.—Mugearite. From east side of road, Covin Hill, x 25.

FIG. 2.—Analcitised Basalt, showing phenocryst completely replaced by analcite in which are numerous small prisms (dark patches) of ægirine-augite. From the shore, 300 yards north-east of Port Leithne, x 25.

FIG 3.—Ophitic Dolerite, showing two grades of texture. From north and south Kainozoic Dyke, Dunagoil Bay, x 20.

FIG. 4.—Coarse ophitic olivine-dolerite. From coarse vein in Permo-Carboniferous sill, shore, Port Leithne, x 10.

FIG. 5.—Epidiorite; clear areas are quartz and felspar, hornblende, chlorite and magnetite are other constituents. From top of ridge, 100 yards south of the Dun, Scalpsie, x 20.

FIG. 6.—Epidiorite showing epidote bulking largely as a constituent. From the shore, north side of Scalpsie Bay, x 20.

PLATE XXXVII.

FIG. 1.—Olivine-pyroxenite; the large clear crystal of olivine, with dark veins of serpentine, exhibits cleavage. This rock of coarse plutonic habit is from the same locality as the anorthosite and dunite shown in Plate B, Figs. 1 and 2. x 40.

FIG. 2.—Junction of vein of porphyritic tachylyte and mugearite. The tachylyte occurs in a small olivine-dolerite sill, 150 yards north of the large olivine-dolerite sill, shore, Run-nan-Eun and the vein of tachylyte also penetrates the mugearite lava. Note the minute xenoliths of mugearite in the tachylyte, x 40.

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No. XXII.—The Annan Red Sandstone Series of Dumfriesshire. By J. Horne, LL.D., F.R.S., and J. W. Gregory, D.Sc., F.R.S.

[Read 13th May, 1915; issued separately 10th February, 1916.

The post-Carboniferous red sandstones of the south-west of Scotland are found in a series of isolated areas which cover about fifty-four square miles. They include two sets of rocks——(1) a succession of strongly false-bedded sub-aerial sandstones, which may be termed the Dumfries Series, and (2) an area of interbedded red sandstones and shales which may be conveniently grouped as the Annan Series. Of the false-bedded Dumfries Sandstones the chief outcrops are around Dumfries, as at Locharbriggs, Lochmaben, Corncockle, Lockerbie, Closeburn, and Moffat. They are also exposed at Loch Ryan, Mauchline in north Ayrshire, and Arran. The interbedded red sandstones and shales extend, north of the Solway, from the neighbourhood of Annan eastward to the English Border.

The differences between these two groups of deposits are so well marked that they have generally been referred to two distinct horizons. The false-bedded sandstones closely resemble the Penrith Sandstones (Lower Permian), and the sandstones east of Annan are equally similar to the St. Bees Sandstone (Bunter), with which direct stratigraphical continuity has been proved around the eastern end of the Solway. The false-bedded Dumfries Sandstones have therefore been generally accepted as Lower Permian and the Annan Sandstones as Triassic. This view was expressed by Harkness in 1850 (p. 397); he concluded from the lithological and palæontological evidence that the sandstones east of the river Annan are superior in position to those of the neighbourhood of Dumfries. He repeated this view in 1856 (p. 267), when he remarked that in south-western Scotland most of the red sandstones were Permian, and the only Triassic rocks on the mainland were those to the east of Annan.

E. W. Binney, who had made a close study of these rocks in Cumberland, visited Dumfriesshire, and also accepted (1856,

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p. 138) the conclusion that most of the red sandstones in the south-west of Scotland are Permian, and that only the Annan beds are Triassic. Murchison,[1] in 1864, in a joint paper with Harkness (pp. 153, 158), also adopted the conclusion that the Dumfries Sandstones are the equivalent of the Penrith Sandstone, and the Annan Sandstones of the St. Bees Sandstone. Mr. T. V. Holmes, in 1881 (p. 288, pl. xi., and 1889, first pl. and p. 237), also accepted this view, and described the western sandstones (Dumfries) as precisely like those of Penrith, and those east of the Annan Water as the representative of the St. Bees Sandstone. This correlation was adopted by H. B. Woodward in "Stanford's Geological Atlas" in 1904 (pl. xxxiv.); by Mr. G. W. Hickling (1909) from the age indicated by the fossil footprints of Corncockle Muir, which he identified as undoubtedly Permian; by Sir Archibald Geikie in 1901 (pl. iii.), and in his Geological Map of Scotland, 1910; and by Mr. Jukes-Browne (1911, p. 208), who accepted the false-bedded sandstones as the equivalent of the Penrith Sandstone, but regarded the breccias and conglomerates as the base of a Triassic series. The breccias must certainly be included with the Permian Sandstones. Mr. R. Boyle in 1909 (p. 345), though grouping all the rocks as "New Red Sandstone," remarked the exceptional nature of those near Annan.

The conclusion has, however, also been adopted that both groups of rocks belong to one system. This view has been expressed on the Geological Survey maps; in the Scottish sheets, No. 10 (1885) and No. 6 (1879), these sandstones were all included in the Permian. After the discovery that some of the Upper Red Sandstones of Arran were Keuper, the whole of the post-Carboniferous red sandstones of the south-west of Scotland, including Arran, were transferred to the Trias (Map 4 miles to an inch, sheet 17, 1904). After re-examination of the red sandstone series in the south-west of Scotland and in Cumberland, we are of opinion that the view that the Annan series is Triassic and the Dumfries and Mauchline Sandstones are Permian is the correct conclusion.

The lithological differences between the two groups of rocks

[1] Murchison had in 1851 (p. 163) insisted that the Dumfries Sandstones are not Triassic but Permian.

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are very striking. The Annan series consists of posts of sandstone interstratified with red shales and containing layers rich in white mica, but no layers of foreign pebbles. The sandstones consist of sharp angular grains of quartz and felspar with abundant white mica. The structure and character of the rock show that it was an aqueous deposit. False-bedding is inconspicuous, though some current-bedding is observed, and some false-bedded bands have been deposited in stream channels cut by contemporaneous erosion. The sandstone is fine in grain; there are no pebbles of any of the lower Palæzoic rocks, though on one horizon of the Annan series there are conglomerates due to the breaking up of interbedded shales. We have not seen any fossils from these rocks. Labyrinthodon footprints have been recorded by Binney (1856, p. 138) from near Annan; various structures from Corsehill have been regarded as fossils, but they are inorganic.

The Permian Sandstones of Dumfries and Mauchline are coarser in grain, and many of the grains have been beautifully rounded by wind erosion; interbedded shale is very exceptional; mica is scarce and often absent; the rocks include some bands of breccia, in which the pebbles are quartzites and graywackes from the pre-Carboniferous rocks; these pebbles are often facetted by wind action, and must have been exposed to sand blast on a desert land. The shape of the grains, the numerous spots and veins of pyrolusite, and the confused false-bedding, which is very conspicuous and is of the sand-dune type, indicate that these rocks were laid down on land under desert conditions.

Reptile footprints are best known in these sandstones from the famous quarry at Corncockle Muir; and Mr. Hickling (1909) has shown that they are of Permian and not of Triassic types.

The two groups of rocks differ in their lithological and palæontological characters. The Dumfries Sandstones are, as Mr. Holmes expressed it, identical in their characters with the Penrith Sandstone, while the Annan Series is known to be of the same age as the St. Bees Sandstone owing to their proved continuity, past Canonbie, with that formation near Carlisle.

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The well-known section at Hilton Beck, near Appleby, includes the northernmost occurrence, west of the Pennines, of Permian dolomitic limestones and plant beds; and this section shows that the St. Bees Sandstone is a later formation than the Penrith Sandstone, the two sandstones being separated by the dolomitic limestone. The balance of opinion is now in favour of including the St. Bees Sandstone in the Bunter, and, if so, the Annan Sandstone is certainly also Bunter. Both the lithological agreement of the Dumfries Sandstone with the Penrith Sandstone and the evidence afforded by the fossil footprints support the conclusions of Murchison, Sir A. Geikie, Harkness, Binney, Holmes, Jukes-Browne, and others, that the areas of the Dumfries Sandstone are outliers of the Penrith Sandstone.

The Annan Sandstone.

Very little has been written about the Annan series. No memoir has been issued by the Geological Survey on the two sheets, 10 and 6, in which these rocks are included. The series comprises a varied succession of shales and sandstones, and, for the convenience of reference and description, the classification proposed for the western and central part of the tract may be summarised as follows in descending order:—

5. Warmanbie Sandstone.
4. Annanlea Sandstone.
3. Woodhouse Tower Sandstone.
2. Robgill Marls.
1. Allerbeck Sandstone.

The Annan series lies unconformably on the rocks of the Carboniferous Limestone series, which are well exposed on the northern and western borders. The Carboniferous rocks are mainly coarse, gritty sandstones, interbedded with some conglomerates, and limestones; and, in addition to the limestones recorded on the map, a red-stained limestone outcrops at Bethankie Bridge.

The Annan series is widely covered by a sheet of glacial drifts, so that rock exposures are few, except in the quarries and the deeper river valleys.

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Warmanbie Sandstone.

This sandstone was exposed in the Warmanbie Quarry, which is to the east of the Corsehill Quarries, where the sandstone dips east beneath it. The rock consists of a series of irregular sandstones and interbedded shales; it is not now worked as the quality is inferior. The quarry is said to have been opened in consequence of the discovery of some good stone in the railway cutting; but the amount of useful freestone in proportion to the useless material is too small for profitable working.

The Annanlea Sandstone.

The Annanlea Sandstone is well exposed in the Annanlea Quarry, which is about 120 feet deep. The freestone is covered by boulder clay on the eastern face of the quarry, but it outcrops beside the railway. Beneath the boulder clay is a 12-feet bank of "sill," the local term for red shale. Then follow 30 feet of freestone, containing six or seven layers of shale, which vary in thickness from a mere parting up to 1 foot. Next in order comes a thin but very persistent band of shale, which is succeeded by 20 feet of freestone, which rests upon an 18-inch layer of shale, the thickest in the quarry; between it and the water at the bottom of the quarry are about 40 feet of freestone with occasional layers of shale. The Annanlea Sandstone is a compact, light red sandstone, composed mainly of sharp, angular grains of quartz and felspar with numerous flakes of white mica. The stone is regularly and thinly bedded. Some of the stone is slightly false-bedded, and some of the layers of shale rest in channels that had been cut in the layers of sand. The false-bedding is much less marked than that of the Permian Sandstones of Dumfries or Ballochmyle, and it is a current-bedding, and not a dune-bedding. All the rock has a fine grain; we have not seen a single foreign pebble in it, though it contains some layers of shale conglomerate due to the contemporary breaking up of layers of clay. Seams full of white mica are numerous, and there is some white sandstone.

The famous quarries at Cove occur on both banks of the

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Kirtle Water, near Annanlea; the older quarry is on the left bank, and the quarry worked in recent years is on the right bank, opposite Annanlea. They show freestone identical in character with that in the Annanlea Quarry; the sandstone posts are separated by the same beds of shale; there are layers of shale conglomerate, and there are numerous channels due to contemporaneous erosion, sometimes composed of shale in sandstone, and more rarely of sandstone in shale. The dip of the rock in one point on the floor of the quarry is 8° to 5° south of west. The amount of shale increases in the lower part of the quarry where the freestone is more flaggy and more argillaceous. The freestone in the large, disused quarry at South Woodhead is indistinguishable from that of Annanlea and Cove, and it is associated with the same micaceous shales and layers of contemporary shale conglomerate. The dip is 9° to 10° west of south. This quarry was opened on the eastern continuation of the Annanlea Sandstone, which probably forms the high ground between the two quarries.

The Corsehill Quarry, 2 miles to the north of Annan, is the oldest of the chief quarries in the district; it has been worked for about a century, and the pits are now in one place 80 feet deep. The freestone is indistinguishable from that of Annanlea, but the quarry as a whole contains a larger proportion of shale. The layers of shale are both more numerous and thicker, so that in places half the vertical thickness is of shale. The contemporaneous erosion channels are exceptionally numerous.

The dip at Corsehill is about 8° to the south-east by south. Some fossils have been reported from the quarry; the specimens are now in the garden of Mr. Murray, the proprietor, but they are only irregular columns of stone, which may have been originally rolled galls or concretions.

The Woodhouse Tower Sandstone.

At the Woodhouse Tower, north of Annanlea, is a coarser grained, rougher sandstone, and a similar rock can be recognised in several quarries. It appears to represent a horizon between the Annanlea Sandstone and the thick marls in the middle of the series. This coarser sandstone is ex-

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posed in the Kirkpatrick Quarry, just east of Kirkpatrick Station; the quarry is now overgrown, but its northern face is vertical and clear. It shows 18 feet of boulder clay, resting on two posts of sandstone, of which the upper is 15 feet thick and the lower 2 feet thick; they are separated by a band of shale. The rock dips 8° to 10° south, and passes beneath some soft sandstones and interbedded shales. The thickest of these sandstones is 8 inches, and there is a total of thirteen beds in 10 feet. We did not notice in the quarry any of the layers of shale conglomerate, or of micaceous shale, or the river-cut channels, which are all conspicuous in the Annanlea Sandstone. The freestone worked in this quarry is probably at a lower horizon than that at Annanlea, and the shales at the southern end of the quarry may represent those which appear at the bottom of Cove Quarry.

The large quarry near Bonshaw Tower is almost entirely overgrown. The rock is exposed only at one point, and it is there coarser in grain than the Annanlea Sandstone; the fact that the walls have broken down indicates that the rock weathers more readily than in some of the other quarries of the district. The railway viaduct at Kirtlebridge is said to have been made from this quarry, and shows the nature of its stone.

The quarry beside the Kirtle Water opposite Kirtlebridge Mill is in a flaggy sandstone resting on a thick post of argillaceous freestone, which remains very moist, and apparently soon softens.

The old quarry at Stapleton Tower shows flaggy sandstones above a post of massive sandstone. The dip is uncertain, as the rocks are not well exposed, but it appears to be northward, and the rocks at this quarry resemble those at the Bonshaw and Kirtlebridge Quarries.

The old quarry at Merkland is overgrown, but its coarse, soft sandstone, with few shale bands, is probably a decayed representative of the Woodhouse Tower Sandstone.

The Robgill Marls.

The middle part of the Annan series consists of a thick bed of red marls, which are well exposed in the river bank at Kirtle-

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bridge, at the Red Scar south of Palmersgill Bridge near the lodge of Springkell, and in the banks of the Kirtle Water between Merkland and Cove. They are there seen to underlie the flaggy, ripple-marked shales below the Woodhouse Tower Sandstones.

The beds are well shown in the river cliffs near Robgill Bridge. On the right bank of the river above that bridge a cliff shows 20 feet of red marl dipping 20° to 30° south of west. Below the bridge at Robgill Tower the base of the section shows 25 feet of red marl, covered by 7 feet of red sandstone interbedded with marl, and this is overlain by 10 feet of massive sandstone. On the opposite bank of the river beneath Woodhouse Tower the marls are exposed in the stream bed, and are at least 70 feet thick. They are covered by ripple-marked shales, which pass into flaggy sandstones, which are succeeded by a 10-foot cliff of finely bedded, slightly false-bedded red sandstone. This sandstone may correspond with that seen in the Kirkpatrick Quarry.

East of Woodhouse Tower the Kirtle Water valley widens, and the gentler slopes of the north bank appear to have been cut out of shale. The right bank of the river is a high cliff, with marls below capped by a massive sandstone. The valley contracts to a gorge with sandstones on both banks; the exposures show the Annanlea Sandstones with interbedded shale and shale conglomerate. The relations of the freestones to the marls to the north is shown near Blackyett House, which stands on the Annanlea Sandstones, which are faulted against the marls. The line of this fault can be traced up the left bank of the river past Woodhouse Cottage. A deep gully has there been cut through the marls, while the bank to the east is formed of the freestone. The fault can be traced eastward to the north of the Annanlea Quarry, where the fault is said to have been formerly seen; it ran past the north face of the quarry, about 36 yards south of the main road, but it is now covered by the dump. The expected extension of the quarry to the north was rendered impossible owing to the marls being there faulted against the sandstone. The presence of the fault immediately to the north of the Annanlea Quarry was also supported by bores which showed the existence of thick beds of the red marls.

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The Allerbeck Sandstone.

The lowest subdivision of the Annan Sandstone series includes a series of shales and soft weathering sandstones which are exposed in many old quarries that are not at present worked. These beds outcrop on the northern and western margins of the area, and the same horizon is exposed at one locality on the south-eastern margin.

The red sandstones on the north-western margin of the Annan Sandstone area are exposed in numerous old quarries north of Kirtlebridge. The quarry on the right bank of the Kirtle Water, south of Kennels, exposes a soft massive sandstone, which weathers easily; it is not interstratified with compact shale bands like the Annanlea Sandstone.

Beside Allerbeck Cottage is a small, old quarry, the walls of which are now mostly covered by fallen material; the only rock exposed is a post of a fine-grained, somewhat harsh sandstone, which soon softens on weathering, and is discoloured by green spots; it is 4½ feet thick. It agrees in character with the rock on the opposite bank of the Kirtle Water. A similar sandstone is exposed in an old quarry at Burnhead.

The rock on the northern margin of the Annan Sandstone area is exposed in quarries beside the Logan and Cadgill Burns. A cliff north of Loganhouse shows an exposure of 15 feet of beds of sandstone and interbedded shales; the sandstone is in layers from 4 inches to 8 inches thick. The dip is 5° to the west. The sandstone is of poor quality, and the clay cement is apparently soon washed out of it, and leaves a soft sand-rock. The old quarry on the north side of the stream worked a soft, coarsely banded sandstone, which is interbedded with micaceous shale.

The quarry at Turner's Lynn, on Cadgill Burn, occurs close to the junction with the Carboniferous rocks. The quarry shows the following section:—

Red boulder clay.

4. Irregular sandstones and shales, 10 feet, of which 7 feet are shales and 3 feet are sandstones.

3. Post of white sandstone, 8 feet thick, including a thin shale parting 2 feet from the top.

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2. Five feet of brick-red laminated sandstone, of which hand specimens are indistinguishable from that of Annanlea.

1. Laminated grey sandstone, 6 feet 4 inches thick.

The general dip is about 15° to the south-west. The best rock is that in the lower part of the quarry. It consists of a coarse, gritty freestone, and is sometimes white. The rock contains no layers of the shale conglomerate, and though some of the layers are slightly micaceous there is nothing agreeing exactly with the micaceous bands of the Annanlea Sandstone. The Cadgill Sandstone agrees in general character with that of the old quarries around Allerbeck.

At Shawrig, beside the Kirtle Water, near Kirkpatrick, are the remains of two quarries in a soft sandstone and sand-rock which is of a kind characteristic of the lower part of the Annan Sandstone series. The sandstone occurs in thick posts separated by shale, but there are no micaceous layers or exposures of shale conglomerate.[2] The dip is 5° to 30° W. of S.

The old quarry on the western bank of the Annan River, near the Annan Cemetery, is close to the western boundary of the Annan Sandstone. The beds dip westward. There is no included Carboniferous material in the stone, which consists of massive posts of freestone. The upper beds are flaggy. The exact position of this sandstone is uncertain.

Owing to the thick cover of glacial drifts the Annan Sandstone series is seldom exposed on its southern border, but outcrops occur on the banks of the Kirtle Water at Redkirk above and below the footbridge west-south-west of Old Gretna. A small quarry near Redkirk Mill shows an 8-foot exposure of thin-bedded red sandstone, in layers varying from ¼ to 3 inches thick. These are separated by red micaceous shales. The red sandstones of the Annan series are also exposed in two outcrops beside the river below the Old Gretna footbridge.

The Permian Sandstone of Dumfries.

Around Dumfries are numerous quarries in the well-known red sandstone series, and the rock in this area presents characteristics strikingly unlike those of the red sandstone found

[2] Some of the rock is a mere sand-rock, and the corners can be broken off by the fingers.

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to the east of Annan. They consist of coarse, red, intensely false-bedded sandstones, interstratified with quartz breccias.

The breccias are well exposed in a long railway cutting south-west of Dumfries; the cutting is in places 30 feet deep, and shows breccia interstratified with some layers of sandstone. Some of the boulders are 1 foot in diameter, and some of the pebbles are standing on end. They are occasionally round, but the majority are facetted, and show angular faces due to sand cutting. We saw no sign of glacial striation, and the arrangement of the pebbles is not like that of a boulder clay, but resembles material that has settled under the action of wind in a stony desert. The sandstone layers are short and irregularly distributed, and are probably due to the collection of layers of sand in small pools.

Closeburn Quarry well illustrates the extreme complexity of the false bedding in these Permian Sandstones. The false bedding is of the sand-dune type, and resembles that of the quarries at Mauchline. In some of the layers the grains are large, and are as well rounded as marbles. There are many streaks and scattered patches blackened by manganese peroxide, a familiar feature of modern desert formations. The rock contains some flakes of mica, but there are no layers so crowded with mica as in the Annanlea Sandstone.

The quarries at Corncockle Muir, famous for its fossil footprints, and the great quarries at Locharbriggs contain extremely false-bedded sandstone; the dip of the true bedding is high, and is in places 40°. At Corncockle there are thin veins of pyrolusite.

Sequence of the Annan Series in the Western and Central Districts.

The general relations of the beds exposed in the western and central parts of the Annan Sandstone area may be summarised in the following table[3]:—

Upper Stage.

(6) Warmanbie Sandstone. Irregular sandstones with shales.

(5) Annanlea Sandstone, a series of fine-grained, regularly bedded sandstones with contemporaneous erosion channels and inter-

3 The extension of these rocks east of the Sark is not included in this paper.

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bedded layers of "sill" or shale, at Annanlea, Cove, Corsehill, and Southwoodhead.

At the base thick shales, as at Cove and southern end of Kirkpatrick Quarry.

(4) Woodhouse Tower Sandstone, a gritty sandstone which is coarser in grain than Annanlea Sandstone.

At Woodhouse Tower; Kirkpatrick Quarry; quarry near Robgill Tower; around Bonshaw Tower; Kirtlebridge Mill Quarry; Merkland; Stapleton Tower.

Middle Stage.

(3) Ripple marked shales at Woodhouse Tower; Robgill; near Bonshaw Tower; Logan Wood, south-west of Chapelknowe; Breckonbeds, one mile south-west of Kirtlebridge; they pass down into

(2) The Robgill Marls, well bedded typical Triassic marls, exposed below Robgill Tower; in the banks of the Kirtle south of Bonshaw Tower; at Kirtlebridge; near Woodhouse Cottage.

Lower Stage.

(1) The Allerbeck and Cadgill Sandstone. Massive soft sandstone and sandrock interbedded with shales; it includes layers of white and grey sandstone. The sandstone is weaker than the Annanlea Freestone and is more retentive of moisture. It is exposed at Newlands south of Blackwood House; Allerbeck Cottage; Allerbeck; Burnhead; Loganhouse; Cadgill. This horizon is represented at Redkirk near Gretna by grey and red sandstone, sand-rock and shales.

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No. XXIII.—The Hurlet Sequence in North Lanarkshire.

By Peter Macnair, F.R.S.E., F.G.S.

[Read 13th May, 1915; issued separately 10th February, 1916.]

I. Introduction.

The Lower Limestone Series in the area about to be described lie to the north of a line drawn from Drumclog, east to Lesmahagow, and thence north-east by Kilncadzow to the Cobbinshaw Reservoir on the confines of Lanarkshire and Midlothian. They form a lip or edge of the basin which has the great Coal Measure Series of Lanarkshire in the centre, and they are bounded on the west and south by the volcanic plateau of Eaglesham and Strathavon, which separates them from the Ayrshire basin, and on the south and east by rocks of Lower Old Red Sandstone and Calciferous Sandstone age. Though now separated from the Lower Carboniferous Limestone area of Renfrewshire and Ayrshire by the volcanic plateau of lavas, at one time the two areas must have been more or less continuous, as can be shown by the occurrence of such outliers of the limestone as we find at Ryeland and Drumclog resting directly upon the lavas. The former continuity of the two areas is also clearly brought out by the identity of the limestone series on each side of the volcanic ridge, as we hope to be able to show that such well-marked horizons as the Dockra or Blackbyre Limestone, the Blackhall Limestone, the Calderwood Cement or top Hosie Limestone, the Slingstone Limestone or top marine band, all with characteristic faunal associations, can be traced over many hundreds of square miles from the neighbourhood of Dalry on the west to the confines of Lanarkshire and Midlothian on the east.

An examination of a geological map will show that the district under consideration includes many of the most notable fossil localities in the west of Scotland. In the East Kilbride district we have such localities as Thorntonhall, Braehead, Craighall, Crosshouse, and South Shields all in the main Limestone, then we have the exceedingly numerous and richly fossili-

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ferous horizons of the Calderwood Cement series exposed in the neighbourhood of East Kilbride, Calderwood Glen, and the Gill Burn at Jacktown. In the Strathavon district the localities at Gallow Hill, in the Netherfield Limestone, and at Waulkmill, in the Blackhall or Foul Hosie Limestone, have also been long known. In the Lesmahagow district the quarries at Boghead and the sections in the Birkwood and Teiglam Burns have yielded extensive suites of fossils to the west of Scotland collectors. When we come to the Carluke district the fossil localities are even richer and more numerous than in those districts just referred to, large collections of fossils having been made from the various horizons from the *Productus giganteus* Limestone up to the Slingstone Limestone by Dr. Rankin, Dr. Hunter, of Carluke(8),* and others. In all these districts the limestone was formerly extensively quarried, but many of these quarries are now filled up or are rendered in other ways inaccessible. Still the numerous artificial and natural sections still available are of the greatest value in working out the sequence. All round the margin of the basin there is a number of quarries which help to elucidate the structure of the ground. There are also numerous more or less continuous stream sections of the greatest value, such as those seen in the Kittoch Water, Calderwood Glen, the Gill Burn, near Jackton; the Avon and its tributaries between Strathavon and Stonehouse, the Birkwood and Teiglam Burns at Lesmahagow, and Fiddler's Burn, Nellfield Burn, and Raes Gill, in the Carluke district.

II. Description of Sections.

Thorntonhall and Braehead.—These quarries are situated about a mile to the south of Busby, and 5 miles to the south-east of Hurlet. They lie on the north-west side of the basin, which it is the object of this paper to describe. Along the railway cutting and in the bed of a small stream near Thorntonhall Station the ashy muds, with large pebbles, are visible. The top of the muds can also be seen in the tramway which runs into the mine. Above this comes a grey shale, succeeded by

* Numerals in ( ) refer to the list of papers enumerated in the Bibliography at the end.

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a black calcareous shale, which is simply a mass of fossils principally brachiopods of the genera *Productus* and *Orthis*. They are mostly, however, in a very crushed condition. On the top of this shale lies the Main Limestone, 10 feet in thickness, which contains bands of *Lithostrotion* and the large variety of *Productus giganteus*. Then follows 2 feet 6 inches of entomostracan limestone and shale, 3 feet of nodular cement with rootlets, a thin parting of entomostracan shale and coal, followed by 1 foot 6 inches encrinital limestone, the whole being capped by shales and thin ironstones, the former containing the rich fauna described by Mr. Neilson(5). About half a mile further to the west at Braehead Quarries a similar but more continuous section may be seen. We have carefully examined the whole length of the somewhat extensive outcrop laid bare in the quarries, and we find that, as a rule, only some 6 feet of the last member of the series can be seen, it being usually topped by a thin layer of boulder clay. It is of great interest, however, to note that Mr. Bennie speaks in his paper(10) of a supposititious limestone 1 foot in thickness, whose existence is inferred from loose blocks lying on the shale. In a future part of this paper we shall attempt to show that it may be the same bed as is seen *in situ* at Arrotshole. This section at once reminds us of the Hurlet group of strata that lies between the Blackbyre Limestone and the Hurlet Limestone, and though sections are now somewhat scarce in that district, yet what can be seen clearly goes to prove that we are here dealing with the same two limestones and their associated strata. Undoubtedly the best section of the Hurlet Limestone and the strata immediately underlying it to be seen in the Hurlet district is that exposed in Arkleston cutting, east of Paisley, and a comparison of it with the Thorntonhall and Braehead sections shows the close resemblance of the strata at the two localities(16). We have shown that what in all probability is the Blackbyre Limestone cropped out to the west of the bridge over the railway at Arkleston. This we compare on palæontological and stratigraphical grounds with the Main Limestone of Thorntonhall. At Arkleston the Blackbyre Limestone is succeeded by a band of nodular limestone associated with fireclay shale and thin bands of dark impure entomostracan

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limestone, which have all the characteristics of the sediments lying above the Main Limestone at Thorntonhall. The succeeding limestone at both localities we take to be the Hurlet Limestone.

Phillipshill.—The next section we have to consider lies about 1 mile to the east of the Thorntonhall Quarries and is here mentioned principally for the purpose of proving the continuity of the outcrop toward the important section exposed still further to the east in the Kittoch Water. The old workings have now been considerably grassed over, but taken along with an exposure seen in a small burn one is left in no dubiety as to the identity of the strata with those seen at Thorntonhall. The pebbly, ashy muds are seen in the burn to pass up into the highly fossiliferous shale at the base of the limestone which has been worked out. The overlying sediments and nodular limestone are succeeded by the top limestone of Thorntonhall.

Kittoch Water.—We now come to the important section exposed on the Kittoch Water from Arrotshole to Little Duncanrig, in which all the principal members of the Lower Limestone Series can be traced(12). Beginning at Arrotshole, we find the Main Limestone of Thorntonhall and Phillipshill resting directly upon the ashy muds with large pebbles, the latter well exposed on the right bank of the stream a little below the waterfall. Further up stream we find the shales and impure limestone with large numbers of entomostraca, the characteristic nodular limestone with rootlets, and No. 2 limestone of the previous sections, which here makes a second waterfall. Above this limestone comes the black shales, yielding an identical fauna with that described from Thorntonhall by Mr. Neilson. The most abundant shell is *Spirifera urei*, which here occurs in great numbers, but which is a comparatively rare shell on other horizons. The accompanying fauna is so strikingly like that seen at Thorntonhall, that taken along with the stratigraphical evidence the identity of the respective beds is unquestionable. These shales can be traced more or less continuously up stream to a third waterfall, below which they appear to pass. This waterfall is formed by a third crop of limestone, and a careful examination of the strata seen in the stream both above and below it convinces us that we are here

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dealing with a third limestone, and not with a repetition of No. 2 limestone by faulting. Singularly enough there occurs below it a nodular limestone with entomostraca and rootlets, which might on superficial examination be mistaken for the somewhat similar bed seen further down stream, but a closer examination will show that it is not the same. Other evidence going to prove that the two beds are on different horizons will be adduced when we come to consider the Calderwood Glen section. Above No. 3 limestone there occurs a bed of shale rich in *Spirifera urei*, and carrying exactly the same faunal assemblage (so far as a rough examination shows) as the shale bed above No. 2 limestone seen further down stream. The further discussion of this question will be left, however, till we consider the Calderwood Glen section. From the third waterfall to the bridge at the entrance to the plantation the stream passes over a series of shales and ironstones, which are clearly on the same horizon as the Crossbasket Ironstone Series of Calderwood Glen. In these is a band of limey ironstone, also seen in the same position in Calderwood Glen. These ironstones and shales continue round the base of the cliff in the plantation above the bridge. At the top of the cliff there is a band of calcareous sandstone with crinoid stems. This probably lies near the base of the main Hosie. The section exposed in the bed of the stream above the railway shows fossiliferous limey shales grading laterally into limey sandstones. These pass up into an encrinital limestone, succeeded by 10 to 12 feet of shales, with ironstone nodules, the Calderwood cement stone, and the *Posidonomya corrugata* shales, which complete the section of the Lower Limestone seen in the Kittoch Water.

Between East Kilbride and Calderwood Glen the Calderwood Limestone Series was formerly worked at Capelrig and Brankumhall. At the former locality a small exposure of the limestone and cement stone is still to be seen, and the débris of the highly fossiliferous shale lying between the limestones is being brought to the surface by the rabbits. From the large number of the crinoid ossicles and from the general character of its fauna this shale can at once be identified as that associated with the Main Hosie Limestone of this district.

Calderwood Glen.—Entering the glen at Crossbasket Bridge,

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a series of sandstones is exposed in the bed of the stream. Further down these are seen to rest upon volcanic detritus and lavas. About 150 yards above the bridge a hard, white, flaky, dolomitic limestone crops out, and is succeeded farther up stream by more sandstones and shales. On the left bank of the stream opposite Basket there is an exposure of fireclay, coal and limey shale discovered some years ago by Mr. R. G. Carruthers, and which yielded to him specimens of *Posidonomya becheri* and *Pterinopecten papyraceus*. With these are associated plant remains. The whole assemblage reminds us at once of the Pendleside fauna of the Carboniferous of the Colne valley. This bed seems to form a well-marked horizon below the Main Limestone, as we shall presently see that Mr. Carruthers has also found it in a similar position at Cot Castle in the Avon. Proceeding up stream we notice on the right bank the débris from the ironstone mines, and near where it terminates there is a crop of limestone. The bottom limestone is exposed in the bed of the stream, where it is seen to rest on a thin bed of coal and fireclay. The limestone, which is 2 feet thick, is a cement in the upper part and crinoidal in the lower. It passes down into a calcareous shale almost entirely made up of the crushed shells of *Productus semireticulatus*, associated with branches of *Lepidodendron*, which at once reminds us of the Blackbyre Limestone of the type locality. The limestone is followed by 6 feet of massive sandstone, on which rests the characteristic nodular limey fireclay found on the same position at Thorntonhall and Arrotshole, and which we have correlated with an exactly similar bed seen below the Hurlet Limestone at Crookston and Arkleston, in the Paisley district. Above this comes 2 feet of entomostracan shale, followed by 4 feet of encrinital limestone, which we consider to be the same as No. 2 limestone at Arrotshole and the top limestone at Thorntonhall.

About 350 yards further up stream, a little above the wooden bridge over which the footpath passes, the same section is repeated on the left bank of the stream, but the strata above No. 2 limestone are better seen than in the last section. On No. 2 limestone rests a bed of shale, followed by sandstone, then more shales, with thin bands of ironstone and impure

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entomostracan limestones, in the middle of which there is a bed of coal. On the top of the shale comes 2 feet of cement limestone with rootlets, which can at once be paralleled with the similar bed found below No. 3 limestone in the Kittoch Water at Arrotshole. This is followed by a thin band of impure entomostracan limestone and shale, on which rests 1 foot 6 inches of encrinital limestone, the equivalent of No. 3 limestone in the Kittoch Water section, and which we regard as the Blackhall Limestone. From this point to the waterfall above Calderwood Castle the sides of the glen are formed by a group of shales with bands of ironstone (the Crossbasket Ironstones), which are succeeded by the thin-bedded sandstones on which the castle is built. These sandstones are seen to cross the stream at the waterfall, where they show a bed of annelid tubes.

About half a mile above Calderwood Castle the Calderwood Limestone Series is well shown in a steep cliff on the left bank of the stream. In the bed of the stream the Main Hosie Limestone appears in two posts, which are separated from each other by 2 feet 6 inches of highly fossiliferous shale. The section from the water to the top of the cliff is as follows:—

	Ft.	In.
(8) Dark Shale with *Posidonomya corrugata*, - -		
(7) Calderwood Cement, - - - - - - -	0	11
(6) Shale with *Posidonomya corrugata*, - - -	7	
(5) Limestone, - - - - - - - - -	1	4
(4) Shale and Fireclay, - - - - - -	11	
(3) Limestone, - - - - - - - - -	1	6
(2) Fossiliferous Shale, - - - - - - -	2	6
(1) Limestone, - - - - - - - - -	4	

This section is so well known that it scarcely requires further description than simply to point out that No. 2 is the equivalent of the polyzoan shale found at Boghead, Brankumhall, and Capelrig, while the Calderwood Cement is underlaid and overlaid by the *Posidonomya corrugata* shales. Still further up stream, and on its left bank, is the escarpment known as the Black Craig, which shows a thick series of alternating bands of ironstone and shale. In the shale near the foot of the cliff is a bed rich in *Lingula squamiformis*, which in all probability marks the position of the top marine band as seen in the Paisley

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district, and which marks the upper limit of the strata at present under consideration.

The Gill Burn, Jackton.—Returning to Thorntonhall, we now trace the outcrop of the limestones round the basin to the exposure in the Gill Burn at Jackton. Evidence of the old workings in the Main Limestone can still be seen at the Hill of Dripp and at Little Dripp, but there is no exposure of the strata. The presence of blocks of limestone at the former locality with bands of *Lithostrotion junceum* tends to confirm, if that were necessary, that we are still on the outcrop of the Main Limestone. The section in the Gill Burn begins about a quarter of a mile to the east of Hole Farm, where a bed of limestone is exposed. The officers of the Survey have joined up this limestone with the Main Limestone of Thorntonhall, but the stratigraphical and palæontological evidence would rather tend to show that it is the Main Hosie. A little further up, the stream is crossed by the Calderwood cement. The shales below have yielded *Productus longispinus*, *P. semireticulatus*, *Posidonomya corrugata*, *Bellerophon urei*, and *Orthoceras lævis*. The shales above the cement contain a similar fauna, and are simply crammed full of *Posidonomya corrugata*. Further up stream comes a series of shales and ironstones on the same horizon as those seen in Calderwood Glen at the Black Craig, and, like them, they contain a band rich in *Lingula squamiformis*, which marks the position of the top marine bed. Still further up stream above Jackton the top of the Main Limestone is exposed.

Jackton to West Drumloch.—Between Jackton and West Drumloch, on the south side of the East Kilbride basin, a series of quarries in the Main Limestones was formerly wrought, but these have been long discontinued, and most of them are now covered up. Perhaps the best section now visible is that seen at Crosshouse, where the Main Limestone is seen to be much broken up with bands of shale. The limestone in this quarry is rich in corals and brachiopods, and in this respect strongly reminds us of the Blackbyre fauna as developed in the west of Scotland. Among the corals the following genera are represented:—*Amplexus*, *Clisiophyllum*, *Chætetes*, *Cyclophyllum*, *Lophophyllum*, and *Lithostrotion*. Amongst the

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brachiopods we have *Productus costatus*, *P. giganteus*, *P. latissimus*, *P. longispinus*, *P. punctatus*, *P. semireticulatus*, and *P. youngianus*, as well as *Orthis michelene*, *Athyris royssi*, *Chonetes polita*, *Rhynchonella pleurodon*, *Spirifera lineata*, *Spirifera urei*, *Streptorhynchus crenistria*, and *Terebratula hastata*.

Boghead.—This locality is situated 2 miles to the west of Quarter Road Station, and crops of the limestone can still be seen on the farms of Boghead, Craigendhill, and Burnhead. Formerly both the limestones and cement were worked, and they present all the palæontological features that have already been described. The fossiliferous shale that lies between the two posts of limestone is exceedingly rich in fossils, and it was from this bed that David Ure(1), and later west of Scotland geologists, made such extensive collections of fossils. This shale is very rich in the remains of crinoids, small corals, polyzoa, entromostraca, and foraminifera. The mullusca and brachiopoda are not nearly so abundant as in the limestones below the Hurlet, but *Discina* and *Crania* occur in great abundance; in fact, the former species might be described as being gregarious upon this horizon. The following are some of the brachiopods that have been obtained from this horizon:—*Athyris ambigua*, *Spirifera trigonalis*, *Chonetes laguessiana*, *Productus longispinus*, *P. scabriculus*, *Crania quadrata*, *Discina nitida*, and *Lingula mytiloides*. Something like 130 species have been recorded from this bed by the Geological Survey. The black shale contains limestone pebbles, which appear to have been bored either by an annelid or a gasteropod, probably by the latter. All the holes are cup-shaped, and vary in size from a pin point to $\frac{1}{8}$ of an inch in diameter. Sometimes only two or three holes are visible on a stone, while others are literally covered with them(11).

Strathavon.—As the sections round Strathavon have recently been described in detail by Mr. R. G. Carruthers(15), it seems scarcely necessary that these should be repeated here further than what is required to keep up the continuity of the sections round the basin, and to express the points in which we differ from Mr. Carruthers in our correlation of the limestones.

Beginning with the old line of quarries on the south side

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of the Powmillon Burn, between Strathavon and its junction with the Avon Water, we note what appears to be the lowest limestone in the district. It is the same as the Netherfield Limestone of Mr. Carruthers. The stratigraphical position and the character of its fauna has long impressed us with the idea that it is on the same horizon as the Craigenglen shales in the Campsie district which we have correlated with the Hollybush Limestone. It can also be traced further to the north in the Hole Burn, where along with the underlying shale it has yielded a similar fauna to that just referred to. About 60 feet above the Netherfield Limestone comes the Basket shell bed, which we have already referred to as occurring in Calderwood Glen. It is exposed near the top of the cliff at Cot Castle, and has yielded a similar fauna to that seen in the Calderwood Glen exposure. The next limestone in ascending order is the Under Limestone, which lies about 100 feet above the Basket shell bed. It is best exposed on the right bank of the Avon, opposite Bankhead, where it is seen to consist of an upper red weathering crinoidal limestone, 3 to 6 inches thick, separated by a thin parting of shale from a lower grey crinoidal limestone which weathers to a bright yellow colour, and contains a few small brachiopods. Below this comes 2 feet of soft, limey shale with *Productus*, followed by blaes containing *Lingula* and plant remains.

About 25 feet above the Under Limestone, and separated from it by a thick bed of sandstone and fireclay, comes the Main Limestone of the Strathavon district, which is well seen on the left bank of the Avon below Glassford Bridge. It rests on an inch or so of foul coal, which passes down into the fireclay, just referred to. The limestone is 5 feet thick, and its distinguishing palæontological feature is the presence of bands of *Lithostrotion junceum* and occasional solitary corals. A number of large slabs of limestone can be seen at Cot Castle Farm, which are covered with *Productus giganteus* and *Productus latissimus*. These slabs, I understand, were taken from the mine in the Main Limestone just below the castle, so that the palæontological evidence available points most clearly to the identity of the Main Limestone of Strathavon with the Main Limestone of East Kilbride, which we have correlated with the Blackbyre Limestone of the Hurlet district.

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The next limestone in ascending order ought to be the equivalent of the first limestone above the Main Limestone of Arrotshole and the second Calmy Limestone of the Carluke district; and a limestone does appear in the cliff section at Glassford Bridge some 40 feet above the Main Limestone. This limestone, however, has been correlated by Mr. Carruthers with the Foul Hosie Limestone of the Carluke district, the second Calmy Limestone of Carluke being evidently regarded by him as being absent in the Strathavon area. In the Survey Memoir to sheet 23 this limestone, and that exposed further up the river at Waulkmill, are regarded as the equivalent of the second Calmy Limestone of the Carluke district.

We were at first inclined to agree with Mr. Carruthers, and to take this limestone as the equivalent of the Foul Hosie Limestone of the Carluke district and the Blackhall Limestone of the Hurlet district. At Glassford Bridge the strata above this limestone are hidden by a covering of boulder clay, but where they are exposed in the bed of the river at Waulkmill they are seen to be covered by shales and ironstones, the former yielding all the characteristic fossils which occur above the Blackhall Limestone of the Hurlet district and the Foul Hosie Limestone of the Carluke district, notably amongst these being the great numbers of *Spirifera urei* so characteristic of the horizon.

If we accept this correlation we are of course faced with the important question, what has become of the second Calmy Limestone of the Carluke district which we take as the equivalent of the Hurlet? Our answer is, that it seems to have died out in this district. Further to the east in the neighbourhood of Lesmahagow we shall see that a thin limestone known as the Psalm Book Limestone occurs above the Main Limestone, being usually separated from it by a thin bed of shale. This might provisionally be regarded as the attenuated representative of the second Calmy Limestone of Carluke. In the Carluke district the second Calmy Limestone appears to vary considerably in thickness when traced from point to point. Dr. Rankin says that it has an average thickness of 20 inches, but it is sometimes 3, and even 6, feet thick. Again, if we refer to the 6-inch-to-the-mile map of the Geological Survey it would appear as if this limestone was regarded as

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absent in certain areas in the neighbourhood of Carluke, as it has not been mapped as occurring between the Main Limestone and the Foul Hosie Limestone. Whatever the ultimate explanation of this apparent discrepancy may be we are convinced that the general sequence is unassailable. In a former paper it has been pointed out that the equivalent of the Hurlet Limestone in North Ayrshire is generally very much attenuated in thickness, being represented by a foot or so of limestone or calcareous shales resting almost directly upon the uneven surface of the Dockra Limestone. We have also shown that there has generally been a break immediately above the Blackbyre Limestone, and that the nature and thickness of the strata which rest upon it are of an exceedingly variable character.

If it could be shown that the limestone exposed above the Main Limestone at Glassford Bridge is the equivalent of the second Calmy Limestone of the Carluke district, and that it is on a lower horizon than that exposed in the bed of the Avon at Waulkmill, then it would afford a much simpler and more satisfactory explanation of the sequence in this district.

The sequence above the Blackhall Limestone in the Strathavon district is remarkably clear, and can now be demonstrated to resemble closely that of the Ayrshire, Renfrewshire, Stirlingshire, and Carluke districts. First comes the Birkfield Limestone, identical with the limestone of that name in the Carluke area, and on the same horizon as the Main Hosie of Ayrshire, Renfrewshire, and Stirlingshire. It is best exposed in the Crumhaugh and Lounsdale Burns. This is succeeded in ascending order by the second and first Kingshaw Limestones, which are the equivalents of the top Hosie Limestone of the other districts just referred to. These, or the position where they have been mined out, can also be seen in the Crumhaugh and Lounsdale Burns. Still higher up the sequence comes the Calderwood Cement or *Lingula* Limestone, also exposed in the Crumhaugh and Lounsdale Burns and in the bed of the Avon near Stonehouse. The top marine band has been detected by the officers of the Survey in the bank of a small burn 350 yards west-south-west of Stonehouse Manse. It is represented by a thin limey ironstone containing *Producti*, and overlain by blaes with *Lingula*, and probably representing the Slingstane or Wee *Lingula* Limestone of Carluke.

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Ryeland and Drumclog.—At these localities there is to be seen a number of exposures of an exceedingly interesting character, as they lie about half-way between the Lanarkshire and Ayrshire basins, and afford a certain amount of evidence for the correlation of the two areas. At this point the two basins are separated from each other by the volcanic plateau of Lower Carboniferous Age. This outlier of the Lower Limestones lies about $4\frac{1}{4}$ miles to the south-west of Strathavon, and extends for a distance of 3 miles in an east and west direction from Ryeland to Meadowfoot. The best and most continuous section is that exposed in a small stream to the north-west of Ryeland. In the stream above West Ryeland-side the volcanic rocks pass up into a series of ashy muds with bands of hard, greenish grits, which are in turn overlaid by calcareous shales full of characteristic Carboniferous Limestone fossils. The most abundant species is *Productus giganteus*, which occurs in great numbers, and along with other species of the same genus is found lying in the shale ventral valve downwards as if they had flourished in placid water and had become silted up without any disturbance. This bed at once reminds us of that exposed on a similar stratigraphical horizon at the head of Paduff Burn, and which we have described in our paper on North Ayrshire. Succeeding this bed in Ryeland Burn there is about 15 feet of shales and ironstones, on the top of which comes the Main Limestone, which at this point must be close on 15 feet in thickness. At the base of the limestone is a shale full of encrinites, over which comes 12 feet of solid limestone capped with some 3 feet of shaley limestone. Resting on the irregular hummocky top of the limestone is an ashy fireclay full of rootlets about 2 feet 6 inches in thickness, and having on the top a thin streak of coal. Above this lies 10 feet of dark shale containing a thin band of ironstone. Near the bottom the shale is rich in plant remains, and contains a bed of *Lingula squamiformis*. The section is capped by beds of shale and thin bands of flaggy sandstone containing plant remains.

We have already noted the strong resemblance of the lower beds to those seen in Paduff Glen, near Kilbirnie. But the even more striking resemblance of the thick limestone to the

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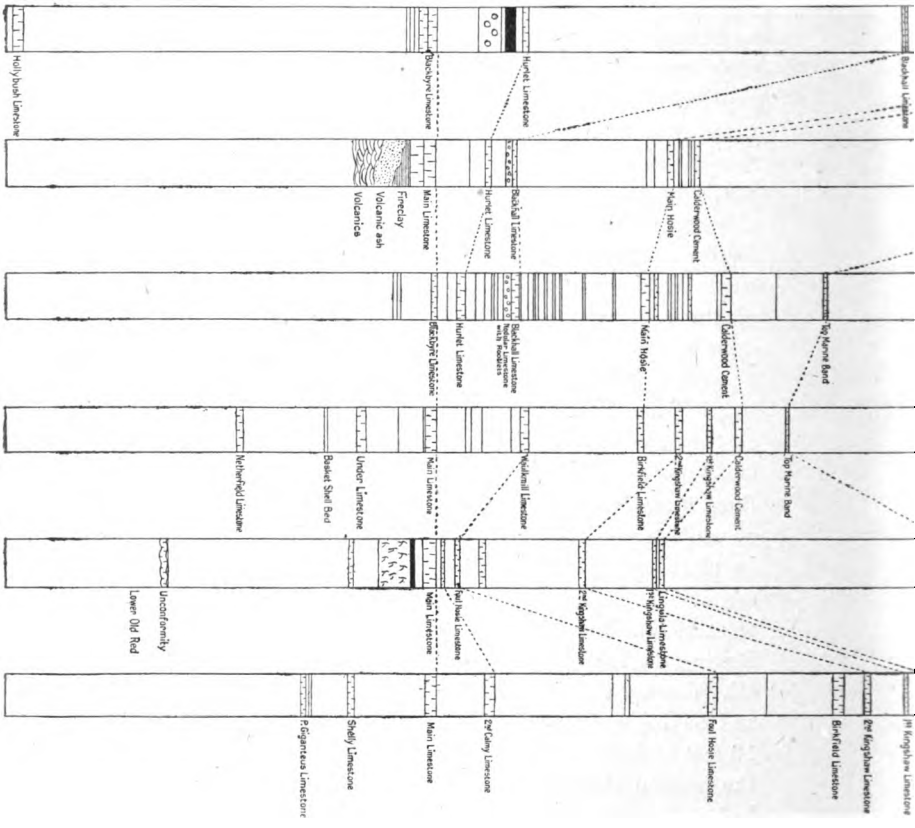
Comparative vertical sections of the Lower Carboni



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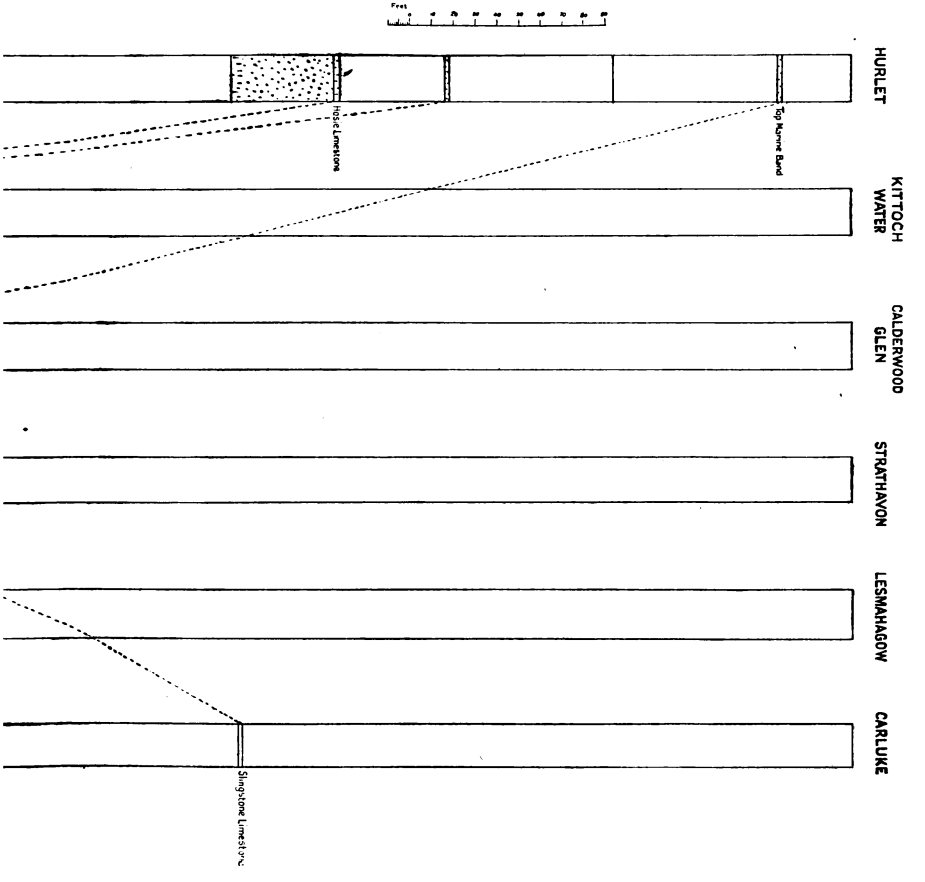
. Limestone Series in North Lanarkshire.

By Peter Macnair.



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Dockra Limestone of Ayrshire cannot but at once arrest attention. The peculiar hummocky top with the overlying green, ashy fireclay containing calcareous nodules, and thin film of coal passing up into beds indicative of estuarine conditions, is so reminiscent of the section at Howwood, Duniflats, Lugton, Beith, Paduff Glen, and other localities in Renfrewshire and Ayrshire that we cannot hesitate for a moment in identifying them all with the top of the Dockra or Blackbyre Limestone position.

Lesmahagow District.—Between the Strathavon and the Lesmahagow districts the crop of the limestone group is seen to be bounded on the south by the Lower Old Red Sandstone Formation, but is separated from it by a strong unconformity which brings the Lower Limestone to rest directly upon the different members of the Lower Old Red Sandstone. The existence of an unconformity at the base of the Limestone Series in the East Kilbride and Strathavon districts has already been pointed out, but, as has been seen in the Lesmahagow area, it is much more strongly marked. Thus in the Birkwood and Teiglam Burns the Limestone Series rests upon chocolate-coloured sandstones and conglomerates which have yielded *Cephalaspis lyelli*, thus showing that the Calciferous Sandstones, volcanics, and Upper Old Red Sandstone groups have been entirely cut out. There is also a considerable overlap of the Lower Limestone group, as is shown by the fact that between the Nethan Water and Hallhill Burn, a distance of 1½ miles, strata varying in position from the Main Limestone to the Lesmahagow Gas Coal are seen to rest upon the Old Red Sandstone. At Boghead, 3 miles north-west of Lesmahagow, the Main Limestone was formerly quarried, but is now completely grassed over. But the fossil lists that have been preserved leave no dubiety that we are here dealing with the Main Limestone. Amongst the corals we have the genera *Alveolites*, *Fistulipora*, *Lithostrotion*, *Lonsdaleia*, and *Syringopora*, whilst the brachiopods *Productus giganteus*, *P. semireticulatus*, and *P. youngii* were also abundant.

Still further to the east the limestones are exposed in the Birkwood Burn. The section commences just where the bridge crosses the road going into Lesmahagow. Resting on

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the Lower Old Red Sandstone and intrusive igneous rocks comes a group of sandstones and fireclays dipping down stream. These are succeeded by a bed of white limestone, about 2 feet thick, rich in large encrinite stems and brachiopods. This is sometimes known as the Wee Limestone, and is probably on the same horizon as the Under Limestone of Strathavon. This view seems to be further strengthened by the fact that it is succeeded by a post of sandstone and sandy fireclay exactly as in the Strathavon area, on which rests the seam of coal and fossiliferous blaes beneath the Main Limestone, the fossils of the latter bearing a close resemblance to those found in a similar position below the Main Limestone of Carluke. Among the more common are plant remains, also *Productus semireticulatus*, *P. longispinus*, *Lingula squamiformis*, *Discina nitida*, *Pteronites persulcatus*, *Axinus deltoideus*, *Leda attenuata*, and fish remains.

Above this comes the Main Limestone, into the old workings of which the stream here plunges beneath the surface, and still further down the stream this is succeeded by two limestones still higher in the sequence, both of which are overlaid by a highly fossiliferous shale carrying the same fauna as that seen above the Waulkmill Limestone on the Avon.

A similar section to that exposed in the Birkwood Burn can be seen further to the east in the Teiglam Burn, in which the Wee Limestone, the Main Limestone, and the two overlying limestones are exposed. Unfortunately the higher strata are cut off at this point by a fault which brings the Carboniferous Limestone Series against the underlying Lower Old Red Sandstone. As in the Birkwood Burn, the shales which lie on the top of the first limestone above the Main Limestone carry a fauna identical with that seen above the Waulkmill Limestone of the Strathavon district, and there can scarcely be any doubt that they are upon the same horizon.

Further north in the bed of the River Nethan, between Burnfoot and Auchenheath, the Lower Limestones are again exposed, the Main Limestone being worked in the pit at Nether Auchtygemmel, from which point it can be traced down to the river, where it is well exposed along with the immediately overlying strata. These beds can be traced for a short distance

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down the Nethan, when they are seen to be faulted against members higher in the series. We have not yet been able to work out this part of the section in detail. But it appears to us that between the fault and the high cliffs of sandstone at the bend of the river the successive limestones represent the Birkfield, the second and first Kingshaw, and the *Lingula* Limestones respectively.

Carluke District.—When the original survey of the Carluke district was made by the Government in 1873(6) the whole area was being opened up by mines and opencast workings for the purpose of obtaining the limestones and ironstones of the series, so that at that time it was much more easy to study the group than it is now, as many of the sections are not now exposed. The records that have been left, both stratigraphical and palæontological, are, however, particularly full and clear, especially those of Dr. Rankin and Dr. Hunter(8), and there can, we think, be little dubiety in correlating the limestones of the Carluke with those of the Hurlet district and the west of Scotland generally. Underneath we give a table showing the succession of the limestones in the Carluke district and comparing it with the type section at Hurlet.

TABLE SHOWING THE PRINCIPAL HORIZONS IN THE HURLET DISTRICT AND THEIR EQUIVALENTS IN THE CARLUKE DISTRICT.*

Hurlet District.	Carluke District.
Lingula Shale and Marine Band, -	Slingstone Limestone.
Johnstone C. B. Ironstone.	
Calderwood Cement, - - -	Lingula Limestone.
Top Hosie, - - - - -	1st and 2nd Kingshaw Limestones.
Lillies Coal and Ironstone.	
Main Hosie Limestone, - -	Birkfield Limestone.
Hosie Sandstone, - - -	Raesgill Ironstones.
Blackhall Limestone, - - -	Foul Hosie Limestone.
Househill Ironstones, - - -	Selkirk Ironstones.
Hurlet Limestone, - - -	2nd Calmy Limestone.
Alum Shale.	
Hurlet Coal.	
Baldernock Limestone.	
Blackbyre Limestone, - -	Main Limeston .
Hollybush Sandstone.	
Hollybush Limestone, - -	Productus Giganteus Limestone.

* Compare with Table given in *Transactions*, vol. xv., page 211.

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Fine sections of the *Productus giganteus* Limestone have been exposed from time to time in the past, though they are not now so numerous. It can, however, be seen in Fiddler's Burn, near Langshaw March. It varies much in thickness, with an average of about 5 feet. In the limestone and associated shales we find numerous fossils, including *Lithostrotion fasiculatum*, *Productus giganteus*, *P. latissimus*, *P. longispinus*, and *P. semireticulatus*. Stratigraphically and faunistically the limestone bears the same relationship to the overlying Main Limestone of the Carluke district as the Hollybush Limestone does to the Hurlet in the Renfrewshire and the Broadstone Limestone to the Dockra Limestone in Ayrshire. About 3 feet above the *Productus giganteus* Limestone there occurs a limey ironstone band, in which *Rhynchonella pleurodon* is the common fossil. This bed can be paralleled with that on the same horizon in Renfrewshire and Ayrshire.

The next limestone in ascending order is the Shelly Limestone, which usually comes on about 30 feet above the last named lime. It is exposed in Nellfield Burn and Braidwood Glen. This limestone is exceedingly rich in brachiopoda, hence its name. It includes different species of the genera *Terebratula*, *Spirifera*, *Athyris*, *Rhynchonella*, *Streptorhynchus*, and *Productus*, young specimens of *P. semireticulatus* being particularly abundant. The limestone, which is about 18 inches in thickness, is probably on the same horizon as the thin band, which occurs in the divisional shales between the Broadstone and Dockra Limestones of Ayrshire, and it may be the same as the thin lime on the top of the Hollybush Sandstone in the Hurlet neighbourhood. The next important bed in ascending order is the seam of coal underlying the Main Limestone, which is succeeded by a strong shale rich in fossils.

The Main Limestone of the Carluke district was formerly extensively worked at Kilncadzow, Langshaw, Mosside, Hillhead, Thornmuir, Bashaw, Waygateshaw, and Milton Lockhart, and can still be seen at some of these localities. It varies in thickness from 3 to 9 feet, and is highly fossiliferous. The general character of the faunal assemblage reminds one at once of the Blackbyre Limestone of Renfrewshire and Ayrshire with its bands of compound corals, solitary corals, and great numbers

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of brachiopods. Hand specimens of this limestone have been gathered containing *Productus mesolobus*, *P. aculeatus*, *Spirifera bisulcata*, *Athyris ambigua*, *Porcellia armata*, and *Lithodendron junceum*. Such specimens serve to give us an idea of the exceedingly rich character of the limestone. A complete analysis of the fauna cannot, however, be given here, but is deferred to a future paper.

The second Calmy Limestone, which we regard as the equivalent of the Hurlet Limestone of Renfrewshire and the west of Scotland, succeeds the Main Limestone. It varies in thickness, having an average of 20 inches, though it is sometimes 3 feet and even 6 feet in thickness. It is separated from the Main Limestone by strata, chiefly shales, from 10 to 20 feet in thickness. The principal palæontological feature of this limestone is the occurrence in it of a band of *Saccammina carteri* found by Dr. Rankin near Braidwood Station. The occurrence of this foraminifer is of some importance, as it helps to link up this horizon with certain others seen further to the east in Linlithgowshire.

The Foul Hosie Limestone, which is the same as the Blackhall Limestone of Renfrewshire, comes on about 18 fathoms above the last, and is 3 feet 6 inches in thickness. It is usually overlaid by a highly fossiliferous shale, which, owing to its characteristic faunal assemblage, it has now been found possible to trace over a very large area in the west, and even into the east, of Scotland. A detailed list of the fossils found on this horizon is given by Dr. Hunter in his Palæontology of the Carboniferous Strata of the West of Scotland. And Mr. Neilson has given us an analysis of the fauna in a paper contributed to the Society in 1911. In the last mentioned paper, after an elimination of the forms having a wide distribution, the following species are given as being more or less characteristic of this faunal assemblage:—*Chonetes hardrensis* (small variety figured by Davidson), *Leda longirostris*, *Nucula luciniformis*, *Dentalium priscum*, *D. inornatum*, *Euomphalus carbonarius*, *Pleurotomaria conica var. decussata*, *Bellerophon oldhami*, *Goniatetes gilbertsoni*, *G. micronatus*, *G. striatus*, *G. vesica*, *Nautilus biangulatus*, *N. subsulcatus Orthoceras cinctum*, *O. dentaloideum*, *O. goldfus-*

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ianium, *O. munsterianum*, and *O. pygmæum*. *Spirifera urei*, a shell comparatively rare on other horizons, is abundant on this, and its large numbers help to indentify the horizon at once. Other abundant forms are *Loxonema curvilinia* and *Cyrtoceras rugosum*.

The Birkfield Limestone, which lies about 9 fathoms above the Foul Hosie Limestone, was 6 feet thick at Birkfield, where it was formerly wrought, and from which locality it receives its name. It is a beautiful encrinital limestone, usually with a reddish tinge of colour, and is regarded by us as the equivalent of the Main Hosie Limestone of Renfrewshire and Ayrshire. A reference to Dr. Hunter's list of fossils from the horizon shows a similar faunal association to that found at Capelrig and Boghead in the East Kilbride area, the shales in association with the limestone yielding an abundant and characteristic crinoid and polyzoan fauna.

The first and second Kingshaw Limestones come on about 8 and 5 fathoms respectively above the Birkfield Limestone. They were formerly exposed at Kingshaw and Birkfield, and can still be seen in Raesgill below Hallcraig. These limestones we consider to be upon the same horizon as the Top Hosie Limestone of Renfrewshire and Ayrshire. The fossil remains on this horizon, so far as yet determined, are somewhat scanty, and do not call for any particular comment.

The *Lingula* Limestone, which is the equivalent of the Calderwood Cement Limestone of Renfrewshire and Ayrshire, is well exposed at Hallcraig Bridge in Raesgill, 1½ miles to the west of Carluke. It can also be seen in Fiddler's Burn at Chapel, 2 miles south of Carluke. The shales associated with the limestone have yielded the well-known fauna that has been so extensively collected in the neighbourhood of East Kilbride, common fossils being plant remains, including *Rhacopteris inæquilatera*, also *Dithyrocaris tenuistriatus*, *Lingula squamiformis*, and *Posidonomya corrugata*.

The Slingstane Limestone.—This limestone, which in the Carluke district is the equivalent of the Top Marine Band of Renfrewshire and Ayrshire, is exposed in Fiddler's Burn, about 300 yards above the exposure of the *Lingula* Limestone at Chapel in the bed of the stream just below the large block

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of sandstone known as "Samson's Slingstone." A detailed examination has not yet been made of the fauna of this horizon, but its principal features are the presence of a bed of shale which is simply a mass of *Lingula squamiformis*, with which are associated limey shales, sometimes passing into limestone, and containing a varied marine fauna. Another outstanding feature of this horizon is the abundant occurrence in the sandstones and limestones of the marine alga, *Spirophyton canda galli*.

From what has been said it will be seen that the principal object of this paper has been to establish the contention that what is generally known as the Main Limestone of North Lanarkshire is the equivalent of the Blackbyre Limestone of Renfrewshire and the Dockra Limestone of Ayrshire, and that the limestones which succeed it can be correlated with one another, as shown in the table on page 400. Some dubiety has arisen and still exists as to the position of the Hurlet Limestone in this area. But the evidence that has been adduced in our opinion serves to show that the second Calmy Limestone of the Carluke district is the equivalent of the Hurlet Limestone of Renfrewshire, while the Foul Hosie Limestone which succeeds it is the same as the Blackhall Limestone of Renfrewshire. The correlation of the limestones higher in the series do not call for any special remark.

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PROCEEDINGS OF THE GEOLOGICAL SOCIETY OF GLASGOW.

SESSION 1914-1915.

Fifty-Seventh Session.

REPORT OF THE COUNCIL FOR 1913-1914.

(Submitted 12th November, 1914.)

The Council beg to submit to the members their Report upon the work and progress of the Society during the past Session, the fifty-sixth of its existence.

The Membership has just about retained the level of last year, when there were 142 ordinary members on the roll, to which falls to be added 17 new members—159. From this we have to deduct the names of 10 resignations, which leaves a balance of 149.

The Finances, which will be reported upon by your Hon. Treasurer, Mr. Wight, show that additional expense has been incurred in the issue of the annual part of the *Transactions*.

The Library work has been fairly active, the circulation of books having been considerably increased, as will be seen from the Report submitted by Mr. Sinclair, the Hon. Librarian.

During the year there were eleven excursions, which were fairly well attended. They were as follows:—

Paduff Burn, Kilbirnie. Mr. J. E. Richey.
Killin, Perthshire. Mr. P. Macnair.
Saltcoats and Ardrossan Beach. Mr. E. M. Anderson.
Stonehouse and Strathavon. Mr. R. G. Carruthers.
Crianlarich. Professor J. W. Gregory.
East Kilbride. Mr. A. Stevens.
Lennoxtown (Campsie Hills). Mr. J. W. Reoch.
Glen Cloy, Arran. Mr. Charles R. Cowie.
Nethercraigs, Paisley. Mr. Duncan Smith.
Bathgate Hills. Mr. G. W. Tyrrell.
Kilmarnock. Mr. C. T. Clough.

During the past Session many papers and notes upon specimens of interest were submitted to the Society at its meetings, which were eight in number, most of which were largely attended. The opening address was delivered by Professor J. W. Judd, C.B., F.R.S., on "Scottish Geologists and the Doctrine of Continuity." The President, Dr. Horne, F.R.S., dealt in his presidential address with the "Canadian Shield." Among some of the more important papers

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we had—Professor Gregory, F.R.S., on "The Red Sandstones of Arran"; Mr. Tyrrell, F.G.S., on "The Boundary between the Upper and Lower Divisions of the Red Rock Series near Whiting Bay and in the Sliddery Water, Arran"; Mr. R. Dunlop on "The Discovery of Chitons and Other Fossils in the Carboniferous of Fife"; Mr. James Wright, junior, and Mr. James L. Begg, "Notes on a Geological Visit to Gothland, Sweden"; Mr. A. Scott, M.A., B.Sc., "A Composite Sill in Glen Cloy, Arran"; Mr. R. G. Carruthers, "Carboniferous Geology in the Strathavon District"; Mr. W. R. Smellie, M.A., B.Sc., on "The Tertiary Composite Sill of South Bute"; and Mr. P. Macnair on "The Hurlet Sequence in North Ayrshire."

Part I. of volume xv. of the *Transactions* was issued in the early part of the Session.

SOCIETY'S ROOMS, 207 BATH STREET, 8TH OCTOBER, 1914.

The first meeting of the fifty-seventh Session of the Geological Society of Glasgow was held here this evening—Mr. G. W. TYRRELL, A.R.C.Sc., F.G.S., in the chair.

The Minutes of the last meeting were read and adopted.

The following were elected Ordinary Members:—Mr. D. W. Fyfe, 11 Melrose Gardens, Glasgow, and Mr. James Borland, 8 Seaford Street, Kilmarnock, both proposed by Mr. C. T. Clough and Mr. E. M. Anderson, and Mr. James S. Wilson, Calgary, Alberta, Canada, proposed by Mr. E. H. Wight and Mr. H. R. J. Conacher.

Mr. H. M. CADELL, B.Sc., F.R.S.E., delivered the opening address on "A Recent Visit to the Alaskan and Klondyke Goldfields," with lantern illustrations.

Mr. CADELL described his visit to the coast of Alaska and to the Yukon Valley and the Klondyke goldfields with the International Geological Congress in September, 1913. He said that the Pacific coast of British Columbia and Alaska was densely wooded and entirely mountainous. The coast range was mainly of granite, and the scenery was like that of the west of Scotland, but more monotonous in colour. As a rule the dark, forest-clad slopes plunge suddenly into the sea without any raised beaches suitable for cultivation or dwellings such as are so useful in Scotland. The whole region has been intensely glaciated as far south as Vancouver, and for the most part swept bare of soil during the Ice Age, but now the great glaciers are melting back in the northern part of the coast at a rapid rate, and some large fjords, now quite accessible, were recently full of ice. Since 1814 the great Muir Glacier had retreated sixty miles and the Reid Glacier, across which the International Boundary Line had been fixed in 1903, at a distance of twelve miles from the ice front, has now melted back beyond the boundary line, and so given to Canada an access to the sea which the United States intended she should not have. This far

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northern harbour, so strangely acquired, is, however, of little value to Canada, as it lies among inhospitable, icy mountains, and if the ice advances again it will be lost.

The region of the Yukon, to the north of these glaciers, is free of ice, and at Dawson and the Klondyke—in the latitude of Iceland—there never have been glaciers, although the ground is all frozen to a depth of 100 feet. In the river valleys are extensive beds of gravel, derived from the ordinary subaerial denudation of the district, in which, at places, gold was found in large quantities in 1898. The dryness of the climate in the Glacial Period prevented ice from forming, and thus there were no glaciers to scour out the valleys and sweep away the gold-bearing gravels, as had probably happened in the glaciated districts.

The Klondyke goldfield, which yielded gold to the value of 4½ million pounds sterling in 1910, is now yielding about one million pounds per annum, and that is produced from the low-grade gravels by the dredgers. Very little is obtained from quartz reefs, which are small and scattered and unlikely ever to be of importance. In the poorer gravels large quantities of bones of living and extinct animals (such as tusks of the mammoth over 11 feet long) are often obtained.

Mr. Cadell described briefly the methods of working the "pay-streak," which lies at the base of the gravels, beginning with the pick and shovel of the individual adventurer of the early days, handling only the richest deposits, through the stage of the small capitalist employing, perhaps, twenty men, and mining with a small steam engine and primitive, home-made plant, to the present time, which is the day of the large, electrically-operated dredger handling profitably material much too poor for the earlier classes of operators.

The population has rapidly declined since the field became unprofitable to the "digger," and has fallen from 25,000 (the figure at the time of the boom) to about 2000.

Mr. Cadell also described some of the glacial phenomena observed on the coast, and pointed out their bearing on familiar features of the glacial deposits of this country.

Mr. Neilson asked if Mr. Cadell was quite sure that what he had taken to be boulder clay lying beneath glacier ice was really clay. He had seen in Switzerland what he had taken to be boulder clay, but closer examination showed it was not clay—there is no boulder clay in Switzerland.

Mr. Stark mentioned that on a steep hillside above Dunoon there is presently exposed an excellent section of glacial beds lying at an extremely high angle, and he asked if Mr. Cadell could suggest how these had been so deposited.

In reply Mr. Cadell said that he did not actually handle the boulder clay to which he referred—it would have been very dangerous to attempt it—but had no doubt as to its identity. He questioned the statement that there is no boulder clay in Switzerland. In reply to Mr. Stark, he suggested that the existence of a stream of water

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between the edge of the glacier and the land would account for such a deposit.

On the motion of Mr. COWIE a hearty vote of thanks was awarded to Mr. Cadell.

JOHN HORNE.

SOCIETY'S ROOMS, 207 BATH STREET, 12TH NOVEMBER, 1914.

The second meeting of the fifty-seventh Session was held here this evening at eight o'clock—Dr. JOHN HORNE, F.R.S., F.G.S., *President*, in the chair.

The Minutes of last meeting were read and adopted.

The following were elected members:—

As Ordinary Member—Mr. William Feely, 127 Glebe Street, Glasgow, proposed by Mr. Peter Macnair and Mr. H. R. J. Conacher.

As Lady Member—Miss Agnes L. I. Forrest, "Clydebank," Ladywell Road, Motherwell, proposed by Mr. W. R. Smellie and Mr. H. R. J. Conacher.

As Associate Member—Mr. Alex. Wilson, 26 Westland Drive, Whiteinch, proposed by Mr. Peter Macnair and Mr. Harry R. J. Conacher.

The Annual Reports for the Session 1913-1914 were read—

(*a*) Council Report by Mr. Peter Macnair and Mr. Harry R. J. Conacher, Hon. Secretaries.

(*b*) Financial Report by Mr. E. Hall Wight, Hon. Treasurer.

(*c*) Library Report by Mr. Wm. Sinclair, Hon. Librarian.

In moving the adoption of the Reports, Mr. C. R. COWIE pointed out that the Financial Report was unsatisfactory in that it showed an excess of expenditure over income of about £15, even after taking into account the donation of £10 which had been made by a member to aid in the publication of the *Transactions*. This position could be met by (*a*) economising in the scale of publication of *Transactions* or discontinuing their issue for a time; (*b*) making a charge to members for copies of *Transactions* (as provided for in the Constitution); (*c*) reducing the outlay on the Library; (*d*) by various minor economies in working; and (*e*), most vital of all, a substantial increase of membership.

It was felt by the Council that economising in publication of *Transactions* or discontinuing their issue for a time, or reducing the outlay on the Library were undesirable courses as likely to impair the usefulness and standing of the Society, but that expenditure on these items should be very carefully made; an expression of the members' opinion on (*b*), making a charge to members for copies of *Transactions*, was desired by the Council, while a way was already seen to make several minor savings which would always help. The brief discussion showed that the line proposed to be adopted by the Council

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had the support of the members. The Reports were unanimously adopted.

The following office-bearers were elected:—

As President—Prof. J. W. Gregory, D.Sc., F.R.S., F.G.S., proposed by Mr. Joseph Sommerville, Mr. John Renwick, and Mr. Wm. Sinclair.

As Vice-President—Mr. R. G. Carruthers, proposed by Mr. Charles R. Cowie and Mr. J. G. Roberts.

As Members of Council—Mr. David B. Duncanson, B.Sc. (Lond.), proposed by Mr. Peter Macnair and Mr. H. R. J. Conacher; Mr. J. V. Harrison, B.Sc., proposed by Mr. W. R. Smellie and Mr. H. R. J. Conacher; Mr. J. Neilson, proposed by Mr. G. W. Tyrrell and Mr. Archd. Shanks; Mr. James Stark, proposed by Mr. Charles R. Cowie and Mr. W. R. Smellie.

As Hon. Secretaries—Mr. Peter Macnair, F.R.S.E., F.G.S., and Mr. Harry R. J. Conacher, proposed by Mr. W. R. Smellie and Mr. P. A. Leitch.

As Hon. Treasurer—Mr. E. Hall Wight, proposed by Mr. Archibald Shanks and Mr. Wm. Sinclair.

As Hon. Librarian—Mr. Wm. Sinclair, proposed by Mr. P. A. Leitch and Mr. Duncan Smith.

Dr. JOHN HORNE, F.R.S., F.G.S., the retiring President, delivered an address on "The Tectonics of the Rocky Mountains and the Selkirks." The address gave an outline of the structure of these mountain ranges as worked out by Canadian and American geologists and laid before the members of the International Geological Congress in 1913. The main lines of section which were examined in the course of the transcontinental excursion C1 were described and illustrated by maps and diagrams and lantern slides.

After a brief reference to the geological features of the great plains between Winnipeg and the foothills of the Rockies west of Calgary, the structure of the eastern and western portions of the Rockies was discussed. Clear evidence has been obtained in the eastern portion of powerful overthrusts in post-Cretaceous time. The strata affected by these movements range from Devonian to Cretaceous. The strike of the strata and the trend of the great lines of displacement are more or less parallel with that portion of the mountain range. The bedding planes of the thrust masses dip to the west and the planes of the overthrust faults are inclined in the same direction, showing that the movement must have been from west to east. The splendid development of the Cambrian rocks, with an estimated thickness of 18,000 feet in the central and western Rockies was next described. Special attention was directed to the rich fossiliferous zone in the Middle Cambrian division of Mount Stephen. Here the observer is struck by the absence of plication and overthrust faulting so conspicuously developed in the eastern part of the chain.

Westwards in the Selkirks there is a vast thickness of conformable unfossiliferous sediments termed by Professor Daly "The Selkirk Series," which are supposed to rest unconformably on the Archæan

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rocks of the Shuswap Lakes. The various divisions of the Selkirk Series were indicated, and the views of Dr. Walcott and Professor Daly regarding the conditions of deposition and geological structure of these pre-Cambrian rocks of the Selkirks were summarised.

Mr. STARK moved a vote of thanks to Dr. Horne, which was heartily given.

Mr. PETER MACNAIR exhibited a series of specimens illustrating the fauna of the Hurlet Alum Shale, which he had found to be an important stratigraphical mark right across the Scottish Midland Valley.

SOCIETY'S ROOMS, 207 BATH STREET, 10TH DECEMBER, 1914.

The third meeting of the fifty-seventh Session of the Geological Society of Glasgow was held here this evening—Professor GREGORY, F.R.S., F.G.S., in the chair.

The Minutes of last meeting were read and adopted.

The following were elected Ordinary Members:—Mr. R. S. Chambers, Carbarns, Jerviston Road, Motherwell; Mr. E. J. Edwards, The Royal Technical College; Mr. Duncan A. M'Vean, M.A., 28 Stewartville Street, Partick; Mr. P. J. Robinson, A.M.I.C.E., Moverons, Allanshaw Road, Hamilton; Mr. Thos. M. Weir, 224 St. Vincent Street, Glasgow.

Mr. FREDERICK MORT, D.Sc., M.A., F.G.S., F.R.S.G.S., read a paper on "Glacial Erosion in North Arran." At the outset he stated that North Arran formed a natural region possessing a marked individuality and homogeneity. The picturesqueness of its scenery and the scientific interest of its natural history have made it a favourite resort with all classes. The mountains of North Arran rise from a remarkably flat plateau which encircles all the peaks, and for which the speaker proposed the name of the "Thousand foot platform." A description of the most characteristic features of the North Arran glens was then given, and many abnormal phenomena pointed out which could only be explained on the hypothesis of vigorous ice erosion. A method was described by which a quantitative estimation of the amount of glacial deepening could be made. Examples of "hanging valleys" were quoted, and it was shown that they were the cause of several picturesque waterfalls. Other glacial features of North Arran, such as corries, spur truncation, and destruction of watersheds were then described and their origin discussed. The remarkable contrast between the rugged scenery of the eastern mountains and the smooth outlines of the western mountains was then considered. Sir A. C. Ramsay's theory that the contrast is due to a difference in rock texture was criticised and rejected. The speaker adduced evidence to show that the cause was the stage to which glacial erosion had attained in the two areas. It was shown finally that the configuration of the sea floor around Arran gave support to the view that many of the

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most characteristic features of the landscape were due to erosion by ice. The various points of the address were illustrated by maps, diagrams, and lantern slides.

Professor GREGORY, whose views on the subject had been assailed, replied to Dr. Mort's criticism, and explained his own views on the North Arran glens and also those of Loch Long, which had been referred to.

Mr. C. R. COWIE expressed his appreciation of the paper and of the many new points brought forward.

The discussion was adjourned.

JAS. STARK.

SOCIETY'S ROOMS, 207 BATH STREET, THURSDAY, 14TH JANUARY, 1915.

The fourth meeting of the fifty-seventh Session of the Geological Society of Glasgow was held here this evening—Mr. JAS. STARK in the chair.

The Minutes of last meeting were read and adopted.

The following were elected members:—

As Ordinary Member—Mr. James M. Fraser, 169 Berkeley Street, proposed by Mr. W. R. Smellie and Mr. J. V. Harrison.

As Associate Members—Miss J. B. Trench, M.A., 1 Springfield Terrace, Crossmyloof; Mr. W. F. Burnett, M.A., 336 Pollokshaws Road; Mr. Wm. Low, 40 Claremont Street; Mr. C. Raeburn, 28 Wilton Drive, Kelvinside; Mr. David G. Ramsay, 1 Lennox Avenue, Scotstounhill—all proposed by Mr. J. V. Harrison and Mr. W. R. Smellie; Mr. William Shields, 32 White Street, Partick, and Mr. William Malloch, c/o Sir Wm. Arrol & Co., Limited, Water Row, Govan—both proposed by Mr. Peter Macnair and Mr. Harry R. J. Conacher.

The adjourned discussion of Dr. Mort's paper on "Glacial Erosion in North Arran" was resumed. Dr. Mort having given a summary of his paper,

Dr. FALCONER said that Dr. Mort seemed to rely a good deal on the opinions of American investigators as to what ice could do and could not do, but he considered that these opinions should be received with caution. He thought that the sculpturing of Arran could not be considered as a thing apart from that of the mainland, and there being clear evidence of the river action on the adjacent mainland, it was inconceivable that Arran should have escaped, and therefore he was convinced that the Arran Valleys owed their origin to river action, and ice had merely imparted a finish to the form. He thought it possible that the present difference of scenery in east and west might be due to frost action acting unequally on the retiral of the ice sheet. He considered that corries are due in the first place to pluvial erosion subsequently modified by glacial action, pluvial erosion being the normal type of erosion throughout the world, although its effects might be modified by subsequent desert or glacial action.

Mr. HARRISON quoted a number of features in Arran which did not seem to fit in with Dr. Mort's ideas.

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Mr. SCOTT agreed that Ramsay's explanation of the differences in the scenery of the Arran granite is not valid. He mentioned a number of corries which are not in accord with the idea that such features face between north and east, and said that while the drainage of the granite area is roughly radial there are important exceptions, some of which probably represent pre-glacial rivers following fracture lines.

Mr. NEILSON pointed out that the thousand feet platform of marine denudation coincides with the junction of the granite and the schists; none of the latter occurs above the platform, and the granite is not cut into. He thought the glens owed their origin to water action and their position to lines of weakness; in some cases they can be seen to follow the line of a dyke. He said that dykes were the cause of some of the most remarkable features of Arran, and agreed that the jagged outlines were due to the existence of thin ridges.

Mr. MACNAIR demonstrated with the aid of models that the most that ice could do was really very slight, and that differences in form were due to alternation of hard and soft rocks. He thought that the difference of scenery between the east and west of Arran was due to the one part having been exposed to sub-aerial erosion while the other was protected.

In reply, Dr. MORT said that he did not pin his faith to the American investigators, but he considered that water action would not explain the known facts so well as semi-glacial, semi-water action. He agreed with Dr. Falconer's views as to the part played by original water action, and thought its effects had been modified later by fairly vigorous ice work. Dr. Falconer and Mr. Macnair suggested that the smoothness of the western hills was due to their having been protected from sub-aerial denudation by an ice sheet, but he knew of no evidence to support the view that ice had ever submerged these hills. He admitted the frequent effects of joints, and agreed with many of Mr. Harrison's points. He also agreed with Mr. Neilson's remarks about the influence of such lines of weakness as dykes, but considered neither differences in rock texture nor the presence of faults, dykes, or joints, adequate explanations of the observed facts. He was quite conscious that, as Mr. Macnair had pointed out, the effect of glacial erosion was relatively slight, but it gives a very definite character to the scenery.

Professor GREGORY read a paper on "The Age of Loch Long, and its Relation to the Valley System of Southern Scotland." [See *Transactions*, p. 297.]

Mr. CADELL said he disagreed with Professor Gregory's published opinion that the lines of lochs and glens were fixed by fault lines. For instance, there is no fault down Loch Lomond nor along Loch Long; there are lines of weakness and master joints, but these are Palæozoic. He did not think the Tweed had been such a big river as was suggested, but the pre-eminence of the Forth was shown by the size of its firth.

Professor GREGORY said that, as the drainage had passed out by

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the Tweed for relatively a short time, naturally a smaller feature than the Firth of Forth had been produced. He thought that it was the gaping of the joints after uplift which had determined the line of the glens. He noted that it was agreed that the lower part of Glen Croe was the work of water, and the striæ present show it to be pre-glacial. It is well known that rivers can cut very irregular beds, going deep in soft rocks and becoming shallow on hard rocks; thus the Yangtse Kiang had made holes to a depth of several hundred feet below sea level. J. W. GREGORY.

SOCIETY'S ROOMS, 207 BATH STREET, 11TH FEBRUARY, 1915.

The fifth meeting of the fifty-seventh Session was held here this evening—Professor GREGORY in the chair.

The Minutes of last meeting were read and adopted.

The following were elected members:—

As Ordinary Members—Mr. James Anderson, 205 Albert Road, Pollokshields, proposed by Mr. P. A. Leitch and Mr. Percy J. Robinson; Mr. A. G. Miller, Strathmore Road, Hamilton, and Mr. W. Fletcher, West View, Scott Street, Hamilton, proposed by Mr. P. Macnair and Mr. Harry R. J. Conacher.

As Associate Members—Mr. T. D. Hunter, M.A., Walker Terrace, Tillicoultry, proposed by Mr. W. R. Smellie and Mr. J. V. Harrison; Mr. W. C. Anderson, 48 Breadalbane Street, Glasgow, proposed by Mr. Alex. M'Lean and Mr. H. R. J. Conacher.

On behalf of Mr. John Renwick, Mr. A. A. YOUNG gave notice that at next meeting Mr. Renwick would move "That the sum of £15 be voted from the funds of the Society for Library purposes during the current Session."

The CHAIRMAN intimated that Mr. Jas. Neilson had that evening presented to the Society sixteen bound volumes of valuable geological works, largely reprints of papers on local geology, which would form a most useful addition to the Library. The thanks of the meeting were awarded to Mr. Neilson. [See p. 422.]

Mr. ALEX. M'LEAN read a paper entitled "Notes on the Geology of the North Berwick Coast." With the aid of diagrams, Mr. M'Lean described the succession of the rocks in the immediate neighbourhood of North Berwick, consisting mainly of products of volcanic activity in Calciferous Sandstone times. The lavas range from basalts to acid trachytes, and their chemical constitution varies with their geographical distribution, the more basic lying to the east and the acid to the west of the district. A consistent order can also be traced in the vertical succession. Tuffs represent a considerable proportion of the total accumulation, and these vary from exceedingly coarse agglomerate to very fine ash with a beautiful bedded structure. Interbedded with the volcanic rocks are ordinary sediments consisting of sandstones, mudstones, and some geyserites.

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Mr. W. R. SMELLIE, B.Sc., read a paper on "The Igneous Rocks of Bute," which was illustrated with lantern slides and microscopic sections shown by means of the projection-microscope. [See *Transactions*, p. 334.]

Mr. HARRISON pointed out that they had in use that night for the first time a new piece of apparatus in the shape of a projection microscope, which they owed to the skill and energy of Mr. Duncanson. He asked for a vote of thanks to Mr. Duncanson, which was cordially given.

J. W. GREGORY.

SOCIETY'S ROOMS, 207 BATH STREET, 11TH MARCH, 1915.

The sixth meeting of the fifty-seventh Session was held here this evening—Professor GREGORY in the chair.

The Minutes of last meeting were read and adopted.

Mr. James Hamilton, 208 St. Vincent Street, Glasgow, proposed by Mr. R. W. Dron and Mr. H. R. J. Conacher, was elected an Ordinary Member.

Mr. JOHN RENWICK proposed, and Mr. CONACHER seconded, that the sum of £15 be voted from the funds of the Society for the purposes of the Library during the current Session. This was unanimously agreed to.

Professor GREGORY referred to the loss which the science of geology had suffered through the recent death of Prof. James Geikie, who was an honorary member of the Society. Professor Geikie's labours in the field of glacial geology had won him a world-wide reputation and had been of very great value to that branch of the science. Prof. Gregory moved that the sympathy of the Society should be conveyed to the widow and family. This was unanimously agreed to.

Mr JOHN V. HARRISON, B.Sc., read a paper on "The Girvan Landslip." [See *Transactions*, p. 313.]

Mr. E. J. EDWARDS mentioned that the resistance of rocks to compression and their weakness to tension was remarkably demonstrated by a recent occurrence near Carnarvon. A large bing of refuse from the quarries in the Yr Eifel microgranite put such a pressure on the underlying inclined sheet of boulder clay that it burst upwards at the foot of the bing with such suddenness that a farmer in the vicinity at the moment had a narrow escape.

Mr. D. A. M'VEAN, M.A., exhibited a series of minerals from Bute, consisting of calcite in various forms, jasper, quartz, agate, &c.

Mr. JOHN V. HARRISON, B.Sc., read "Notes on the Geology of the East Kilsyth Hills." [See *Transactions*, p. 315.]

The features of various rock types were demonstrated by means of the polarising micro-projector.

G. W. TYRRELL.

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SOCIETY'S ROOMS, 207 BATH STREET, 8TH APRIL, 1915.

The seventh meeting of the fifty-seventh Session of the Geological Society of Glasgow was held here this evening—Mr. G. W. TYRRELL, *Vice-President*, in the chair.

The Minutes of last meeting were read and adopted.

The following new members were elected:—

As Associate Members—Mr. A. Sutherland, 12 Regent Park Square, Strathbungo, and Mr. P. Austin, 53 Hamilton Street, Govan, both proposed by Mr. Peter Macnair and Mr. H. R. J. Conacher.

On the motion of Mr. John Renwick, seconded by Mr. J. G. Roberts, Mr. A. M'Intyre and Mr. Alex. M'Lean were re-elected auditors for the current Session.

Mr. DUNCAN SMITH exhibited hazel nuts and wood found in March, 1914, when preparing foundations for the restoration of Paisley Abbey. The occurrence was investigated by the Rev. C. A. Hall and Mr. Smith, who found that the nuts were in great abundance, mostly in pockets, in a gravel about 11 feet from the surface. Consideration of the evidence led to the conclusion that the nuts, and other vegetable matter associated with them, had been accumulated at the time of the 25 feet beach. The nuts were found immediately below the west window of the north wall of the Abbey choir, with fragments of hazel wood, willow stumps, and unrecognisable vegetable matter. The section was as follows:—

Forced earth of graveyard,	- - -	about 2 ft.
Sandy mud (level about 23 ft. above O.D.),		,, 2 ft.
Red Stained Gravel, probably a river gravel,	-	— 1½ in.
Sandy clay passing down into sand,	- - -	8½ ft.
Gravel with pockets of nuts (strike about N.N.W.),		3 ft.
Firm Blue Clay, like topmost layers of Arctic Shell Clay of Seedhill.		

Mr. ROBERTS stated that in the course of working a clay pit near Northampton a similar deposit had been found. Nuts and wood were mixed with bones of Bos longifrons and Bos taurus, the vegetable matter being finely coated with vivianite; the conclusion of the Northamptonshire naturalists was that the deposit had been accumulated in an abandoned channel of the River Nen.

Dr. DAVID ELLIS read a paper on "Fossil Moulds and Fossil Bacteria."[1] He outlined briefly the characteristics of the living representatives of the two groups of organisms referred to, and said that it was about eighty years since fungi had been recognised in the fossil state, and several species had already been named. The subject had received the attention of Worthington Smith, Felix, Williamson, and Renault. Being particularly interested in the iron bacteria it had occurred to him to examine a series of microscopic sections of Mesozoic ironstones with the object of discovering whether they contained any evidences of the existence of members of that group at the period of formation. He had not succeeded in tracing iron bacteria in these

[1] *Proc. Roy. Soc., Edin.*, vol. xxv., part i., pp. 110-133.

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rocks, but had found the remains of moulds which had possessed a similar power to deposit iron oxide on their membranes. The delicate hyphæ were found ramifying through fragments of organic matter, showing reproductive organs and branching portions. He found the evidence so definite that he felt justified in naming the organisms but not in relating them to modern species. He had found these organisms in the ironstones of Lincolnshire and of Raasay. In examining a thin section of a nodule from the Gault near Folkestone he had detected the presence of bacteria, represented by both bacilli and cocci, whose size and characteristic appearance left no room for doubt as to their identity. The paper was illustrated by a fine series of micro-photographs.

In reply to points raised in the discussion by Professor Gregory, Mr. Tyrrell, and others, Dr. ELLIS said that he did not think there was a possibility of his having been misled by deceptive appearances. He could not suggest how such delicate organisms had been preserved, but the fact remained that they were there in the rocks.

G. W. TYRRELL.

SOCIETY'S ROOMS, 207 BATH STREET, 13TH MAY, 1915.

The final meeting of the fifty-seventh Session was held here this evening—Mr. G. W. TYRRELL, *Vice-President*, in the chair.

The Minutes of last meeting were read and adopted.

The following were elected members:—

As Lady Member—Mrs. Julius Pohlman, 27 Hamilton Park Terrace, West.

As Ordinary Member—Mr. J. J. Hunter Johnston, 46 Bath Street, Glasgow. Both proposed by Mr. Macnair, seconded by Mr. Conacher.

Professor J. W. GREGORY read a paper by himself and Dr. Horne on "The Annan Red Sandstone Series of Dumfriesshire." [See *Transactions*, p. 374.]

Mr. MACNAIR agreed with Professor Gregory in the views he had expressed, and stated that the absence of clayey matter from the Dumfries Sandstone was emphasised in a series of analyses of both types which he had occasion to study recently.

In reply to points raised in the discussion, Professor GREGORY said that he thought the material of these sandstones must have come from land lying to the north or north-west. He did not think that the absence of volcanic material from the Trias and its presence in the Permian could be taken as a means of separating the two series, as it could be argued that the volcanic activity of the Permian was dying out as the Triassic areas were approached.

Mr. PETER MACNAIR read a paper on "The Hurlet Sequence in North Lanarkshire." [See *Transactions*, p. 387.]

Mr. NEILSON congratulated the author on his paper, but did not quite agree with him in his reading of the section at Thorntonhall.

J. W. GREGORY.

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COMPLETE LIST OF BOOKS PRESENTED TO THE GEOLOGICAL SOCIETY OF GLASGOW BY JAMES NEILSON, Esq.

No. of vols.

3 "The Fossil Flora of Great Britain," by Lindley & Hutton.
2 "The Silurian System," by Roderick I. Murchison, 1839. Presentation copy inscribed by the author to Thomas Phillips, the author of "The Geology of Yorkshire."
6 "The Geologist" (complete), containing Davidson's "Scottish Brachiopoda."
8 Prize Essays of the Highland Society, containing "Geology of Lanarkshire" (John Craig), "Geology of Carluke" (Dr. Rankin), "Geology of Renfrewshire," &c.
1 Various Papers on the Parallel Roads of Lochaber, by David Milne Home, 1876 and 1877, and Prof. J. Prestwich, 1879.
1 Various Papers on Carboniferous Corals, mainly by James Thomson.
1 Various Papers on Carboniferous Plants.
1 Various Papers on General Palæontology.
1 Various Papers on Scottish Primary Rocks.
1 Various Papers on Silurian Rocks.
1 Various Papers on Rocks and Minerals.
1 Various Papers on Foreign Geology.
1 Various Papers on Boulders.
1 Various Papers on The Great Ice Age in Scotland.
1 "The Great Ice Age," by James Geikie.
1 Various Papers on Natural History.
1 Various Papers on the Primary Rocks.
1 Various Papers on Volcanic Rocks.
1 Various Papers on Glacial Geology.
1 Various Papers on General Geology.
1 Historical and Biographical Papers.
1 Various Papers on Palæozoic Plants.
1 Manuscripts by Dugald Bell (part unpublished).
1 Mammott's "Geological Facts."
1 "The Organisation of Trilobites," by H. Burmeister.
2 Thomson's "Mineralogy."
5 Sections published by the Geological Survey.
3 "British Organic Remains—Fishes, Echinoderms, Trilobites," Memoirs of The Geological Survey of the United Kingdom.
2 Sowerby's "Mineral Conchology."
2 "Annals of Coal Mining and the Coal Trade," by R. L. Galloway.
3 "A Description of the Western Islands of Scotland, including the Isle of Man, comprising an Account of their Geological Structure, with remarks on their Agriculture, Scenery and Antiquities," by J. Macculloch.
2 "A Second Visit to the United States," by Sir Charles Lyell.
1 Brander's "Fossilia Hantoniensia,"

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No. of vols.

3 Parkinson's "Organic Remains of a Former World," with plates.
1 Papers on various subjects, including the Craigleith Fossil Tree, Mineralogy of Disco Island, Polar Ice (Franklin), Fishes and Plants, Burdiehouse Limestone (Hibbert).
1 "The Geology of South-Eastern England," by G. A. Mantell.
1 "Mineralogy," by James Nicol, Aberdeen.
1 Excursions of the British Association, Glasgow, 1901.
1 Excursions of the British Association, Edinburgh.
1 "Dura Den; a Monograph of the Yellow Sandstone and its remarkable Fossil Remains," by Rev. J. Anderson (coloured plates of Old Red Sandstone fishes).
1 "Coal Measure Palæontology," by T. P. Barkas, F.G.S.
1 Atlas of above (Folio).
1 Plates of Pterygotus.

EXCURSIONS—1915.

To Kelvingrove Museum, on Saturday, 27th March—Mr. Peter Macnair, F.R.S.E., F.G.S., conductor. The geological collections were examined.

"A," to Garabal Hill, on Monday, 5th April (Spring Holiday)—Mr. A. Scott, B.Sc., conductor (joint excursion with The Geologists' Association). The party examined the plutonic complex of Garabal Hill and then sailed down Loch Lomond, noting the various features of interest.

"B," to Glen Douglas, on Monday, 5th April (Spring Holiday)—Professor J. W. Gregory, D.Sc., &c., conductor (joint excursion with The Geologists' Association). The party passed around the base of Doune Hill, examining the Dalradian Rocks and the pre-Glacial valleys tributary to Glen Douglas and the glaciated Glen Mallochan. At Luss this party joined, on the homeward journey, those who had gone to Garabal Hill.

To Carmyle, on Saturday, 10th April—Mr. R. W. Dron, C.E., conductor. By kind permission of Messrs. Dunn & Steven the party visited underground longwall and stoop and room workings in the Virgin, Main, and Splint Coals, and saw a coal-cutting machine in operation. The party afterwards proceeded to Foxley Pit to collect the well-preserved specimens of foliage which are found above the Kiltongue coal.

To Paisley, on Saturday, 24th April—Mr. Duncan Smith, F.F.S., conductor. Sections at Jenny's Well and Arkleston Cutting, in the Lower Limestone Series, were examined, as well as the Arctic Shell Clays at Seedhill.

To Larkhall, on Saturday, 8th May—Mr. C. Hawker Dinham, H.M. Geological Survey, conductor. The peculiarities of the district are (*a*) absence by contemporaneous erosion of the top of the Carboniferous Limestone (including the Castlecary and, locally, the Gair), (*b*) absence by overlap of nearly the whole of the Millstone

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Grit, and (*c*) poor development of remaining strata. In the gorge of the Avon Water the Gair, Orchard, Lyoncross, and Index Limestones were seen, as well as the unconformable base of the Millstone Grit, which is only from 8 to 30 feet thick. The plants so far collected show that the time of unconformity coincides with the time of sudden change in the Carboniferous flora discovered by Dr. Kidston, which in Mid Lothian occurs about one-third way up the Millstone Grit, but without apparent unconformity. The most fossiliferous horizon in the Avon Gorge is the blaes above the Orchard Limestone, from which the Survey have recorded Proboscidella nystiana (de Kon), a production new to Scotland. Syringopora from the Lyoncross Limestone is believed to be the first record of this genus from the Upper Limestones.

To West Calder, on Tuesday, 18th May (King's Birthday)—Mr. H. R. J. Conacher conductor. Natural and artificial sections were gone over showing the Lothians Calciferous Sandstone Series from the Ballagan Cementstones to the Hurlet Seam, including numerous exposures of the oil-shales.

To West Kilbride, on Saturday, 29th May—Mr. J. D. Falconer, M.A., F.G.S., &c., conductor. The party noted the dykes and necks of Law Hill, Blackshaw Hill, and Drummilling Hill in the Calciferous Sandstone Series and their effect upon topography. The moraines and basins of the Faulds Burn, with examples of glacial grooves, crag and tail, stream capture, and pre- and post-Glacial drainage were also examined.

To Beith, on Saturday, 12th June—Mr. Peter Macnair, F.R.S.E., F.G.S., conductor. Sections in the Lower Limestone Series were examined in the quarries at Dockra and Broadstone, Beith, and in Kersland Glen and Gurdie Cutting, near Kilbirnie, affording excellent opportunities for collecting.

To Killearn, on Saturday, 26th June—Mr. Wm. Sinclair, conductor. The fine examples of river canyons in the red sandstones at the junction of the Upper Old Red Sandstone and Carboniferous Rocks were visited.

To Turnberry, on Monday, 27th September—Mr. G. W. Tyrrell, A.R.C.Sc., F.G.S. An excursion to Turnberry to examine the igneous rocks of Old Red Sandstone age exposed on the coast section was planned, but had to be abandoned on account of the regretted illness of the leader.

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ABSTRACT

OF THE

TREASURER'S ACCOUNTS.

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ABSTRACT OF THE TREASURER'S ACCOUNTS FOR THE YEAR ENDED 30TH SEPTEMBER, 1914.

CASH ACCOUNT.

RECEIPTS.

To Cash in Bank on Deposit,			£3	0	0
,, Do. in Treasurer's hands,			0	6	7
,, Do. Mr. C. R. Cowie's Donation,			1	13	0
					£4 19 7
,, Subscriptions:—					
Ordinary Members (including 17 new Members)—135 at 10/,			£67	10	0
Do. 2 at 7/6,			0	15	0
Do. Arrears—1 at 10/,			0	10	0
Associates—11 at 2/6,			1	7	6
Life Member,			5	5	0
					75 7 6
,, *Transactions*:—					
Donation from Member towards cost of publication,			£10	0	0
Sales per Hon. Librarian,			4	0	1
Mitchell Library for 40 copies,			2	19	3
Advertisements on Cover,			2	15	0
					19 14 4
,, Interest on Funds,					5 12 10
,, Do. Mr. C. R. Cowie's Donation,					3 10 8
,, Balance due Treasurer,					10 5 11
					£119 10 10

EXPENDITURE.

By *Transactions*—					
Printing and Publishing Vol. XV., Part 1, including cost of illustrations (£10 8s. 5d),	£51	1	4		
Cost of Authors' copies and Reprints of same,	15	1	3		
Postages and Outlays,	1	0	7		
	£67	3	2		
Less Receipts from Authors' for extra copies,	1	15	2		
				£65	8 0
,, Library:—					
New Books and Bookbinding, Maps and Magazines,	£7	19	0		
Librarian's Outlays,	1	0	9		
				8	19 9
,, Administration:—					
Printing and Postage of Circulars and Excursion Booklets, and Advertising,	£22	6	1		
Rent, Insurance, and Attendance,	10	0	0		
Disbursements by Hon. Secretaries, Postages, Stationery, and Petty Expenses,	4	4	1		
Collector's Commission,	0	10	0		
Lantern Expenses,	0	17	3		
				37	17 5
,, Subscription to Marine Biological Association, 1914,				1	1 0
,, ,, to Palæontographical Society, 1914,				1	1 0
,, Mr. C. R. Cowie's Donation—					
Glasgow University, Interest to Martinmas, 1913,	£1	14	2		
Royal Technical College, Interest to Martinmas, 1913,	1	14	2		
				3	8 4
,, Do.—Cash in Treasurer's Hands,				1	15 4
				£119	10 10

LIFE SUBSCRIPTION ACCOUNT.

Sept. 30, 1914.—To Balance to Credit,			£182	10	0
			£182	10	0
Sept. 30, 1913.—By Balance from last Account,			£177	5	0
Sept. 30, 1914.— ,, New Subscription,			5	5	0
			£182	10	0

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ABSTRACT OF THE TREASURER'S ACCOUNTS FOR THE YEAR ENDED 30TH SEPTEMBER, 1914.

Mr. CHARLES R. COWIE'S DONATION.

Sept. 30, 1914.—To Glasgow University, one-half of Interest to Martinmas, 1913,		£1	14	2	
,, The Royal Technical College, Glasgow, one half of Interest to do.,		1	14	2	
Balance to Credit,		101	15	4	
	£105	3	8		
Sept. 30, 1913.—By Balance from last Account,				£101	13 0
Sept. 30, 1914.— ,, One year's interest to Whitsunday, 1913,				3	10 8
				£105	3 8

BALANCE SHEET.

To Life Subscription Account,				£182	10 0
,, Mr. Charles R. Cowie's Donation and accrued Interest,				101	15 4
,, Balance due Treasurer on Cash Account,				10	5 11
,, Capital Account,*				477	4 1
	£771	15	4		
By Invested with Campbeltown Corporation under Mortgage at 3½ per cent.,				£170	0 0
,, Property—Books in the Library,	£440	0	0		
Furniture, Bookcases & Microscope,	60	0	0		
				500	0 0
,, Mr. Charles R. Cowie's Donation—Invested with Campbeltown Corporation under Mortgage at 3¾ per cent.,	£100	0	0		
,, Interest accrued to Whitsunday, 1914,	1	15	4		
				101	15 4
				£771	15 4

* NOTE.—Subject to cost of publishing *Transactions*.

GLASGOW, *6th November*, 1914.—Examined, compared with relative Vouchers and Securities, and found correct, the balance in Treasurer's hands, interest accrued on Mr. Charles R. Cowie's Donation, being One Pound Fifteen Shillings and Fourpence; and the Balance due Treasurer on Cash Account, Ten Pounds Five Shillings and Elevenpence.

ARCH. MACINTYRE,
ALEXANDER M'LEAN. } *Auditors.*

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THE GEOLOGICAL SOCIETY OF GLASGOW.

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Mr. J. W. REOCH (*retires* 1916).
Mr. R. G. CARRUTHERS F.G.S. (*retires* 1917).

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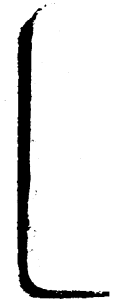

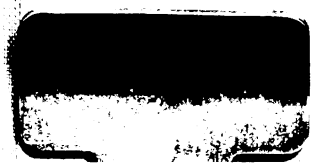

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